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# PUBLIC ROADS ▸▸▸ *A Journal of Highway Research*

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D. M. BEACH, *Editor*

Volume 20, No. 9 November 1939

*The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.*

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# STUDIES OF WATER-RETENTIVE CHEMICALS AS ADMIXTURES WITH NONPLASTIC ROAD-BUILDING MATERIALS

## BY THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTRATION

Reported by **E. A. WILLIS**, Associate Highway Engineer, and **C. A. CARPENTER**, Associate Civil Engineer

DURING the past several years the Public Roads Administration has conducted laboratory and field studies of various types of base-course materials and the factors that influence their behavior in service. The results of two of the laboratory investigations have been published in recent issues of PUBLIC ROADS.[1]

Observation of the behavior of soil road surfaces and the performance of the same materials following the application of bituminous surfaces has suggested the need for laboratory study of this type of construction. Such observations have already established the following facts:

1. Mixtures of granular aggregate and clay binder that form highly stable road surfaces may become unstable as bases when covered with a waterproof surfacing.
2. Nonplastic granular materials, having gradings within definitely established limits, provide stable base courses for relatively thin bituminous surface treatments.
3. These same nonplastic materials when subjected to traffic prior to surface treatment may be loose and dusty in dry weather and the loss of surface metal may be excessive.
4. Moisture films serve to bind such nonplastic aggregates into a coherent road surface.
5. Certain chemicals used either as admixtures or surface applications aid materially in maintaining these moisture films under suitable climatic conditions.

This report describes investigations using the outdoor circular track, shown in figure 1, to determine the effect of the water-retentive chemicals, calcium chloride and sodium chloride, on nonplastic granular mixtures under controlled traffic and moisture conditions both before and after the application of a thin bituminous surface treatment.

The circular track used in these investigations was, with the exception of tire equipment, a duplicate of the indoor track used in the studies previously reported.[1] The test wheels for the outdoor setup were equipped with high-pressure tires, size 30×5, requiring an inflation pressure of 80 pounds per square inch instead of the size 6.00–20 low-pressure tires that were used with the indoor equipment. The load was, as in the indoor track tests, 800 pounds on each wheel. This was increased to 1,000 pounds near the end of some of the tests.

Distributed traffic which was used for compacting and testing the unsurfaced mixtures was obtained by gradually shifting the rotating beam longitudinally with respect to its axis of rotation, causing the wheels to pursue alternately expanding and contracting spiral courses covering the entire track area. Concentrated traffic, which was used after the surface treatment had been constructed, was obtained by locking the sliding pivot of the beam in such a position that the wheels pursued two concentric circular courses whose center lines were about 2½ inches on either side of the center line of the track.

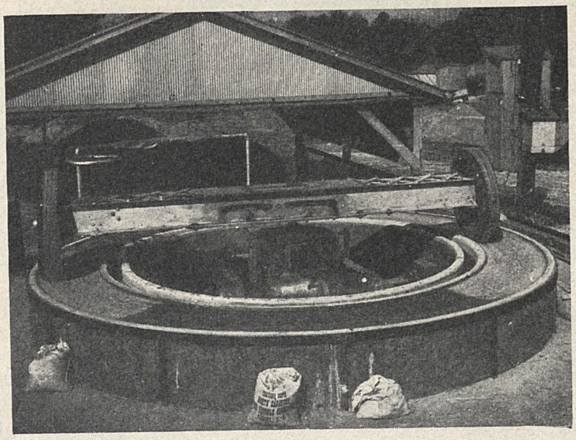

FIGURE 1.—THE OUTDOOR CIRCULAR TRACK USED IN TESTING ROAD-BUILDING MATERIALS. IN THE BACKGROUND IS THE MOVABLE SHED USED TO COVER THE TRACK AT NIGHT AND DURING RAINY WEATHER.

This investigation involved the construction and testing of 20 track sections. Each section was 18 inches wide, 6 inches deep, and approximately 7.5 feet long. Five sections comprised a test track and were tested as a group. Thus four tracks were required to test the 20 sections.

### VARIOUS AGGREGATES AND ADMIXTURES USED IN TEST SECTIONS

The gradings and soil constants of the aggregates used in the 20 test sections are given in table 1. The materials comprising the 15 test sections of tracks 1, 2, and 3 were prepared by combining Potomac River gravel, Potomac River sand, pulverized silica, and a local clay soil having a liquid limit of 41 and a plasticity index of 18.

Crusher-run limestone, blast-furnace slag, and granite were used in the construction of the five sections tested in track 4.

Tracks 1, 2, and 3, except for minor differences in grading incident to slight variations in the stock materials, had identical composition. In section 1 of each of the three tracks the material passing the No. 200 sieve was primarily the clay soil while in all other sections the fines consisted primarily of the inert pulverized silica. Sections 1 and 2 of tracks 1, 2, and 3, had approximately the same amounts of material passing the No. 200 sieve. Sections 3, 4, and 5, differed from sections 1 and 2 and from each other primarily in the amount of mineral dust present.

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[1] A study of Sand-Clay Materials for Base-Course Construction, by C. A. Carpenter and E. A. Willis. PUBLIC ROADS, November 1938. A study of Sand-Clay-Gravel Materials for Base-Course Construction, by C. A. Carpenter and E. A. Willis. PUBLIC ROADS, March 1939.

Table 1.—*Gradings and soil constants of materials used in study of water-retentive chemicals*

| | Track No. 1, section— | | | | | Track No. 2, section— | | | | | Track No. 3, section— | | | | | Track No. 4, section— | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| Grading: | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* |
| Passing 1-inch sieve | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Passing ¾-inch sieve | 98 | 98 | 95 | 96 | 97 | 98 | 96 | 97 | 97 | 98 | 96 | 92 | 97 | 93 | 97 | 100 | 100 | 100 | 100 | 100 |
| Passing No. 4 sieve | 75 | 80 | 66 | 69 | 63 | 76 | 73 | 67 | 62 | 58 | 79 | 67 | 56 | 61 | 59 | 98 | 94 | 65 | 98 | 95 |
| Passing No. 10 sieve | 62 | 69 | 57 | 59 | 52 | 65 | 64 | 56 | 50 | 46 | 66 | 59 | 48 | 50 | 46 | 55 | 63 | 35 | 64 | 56 |
| Passing No. 40 sieve | 40 | 46 | 37 | 35 | 31 | 40 | 43 | 35 | 30 | 26 | 45 | 41 | 33 | 30 | 29 | 25 | 43 | 19 | 41 | 37 |
| Passing No. 200 sieve | 23 | 24 | 18 | 12 | 9 | 23 | 26 | 19 | 12 | 7 | 25 | 22 | 16 | 12 | 9 | 12 | 16 | 5 | 16 | 14 |
| Passing 0.005 mm | 7 | 6 | 5 | 4 | 4 | 8 | 8 | 6 | 5 | 5 | 11 | 5 | 4 | 3 | 3 | 3 | 3 | 1 | 3 | 2 |
| Dust ratio [1] | 58 | 52 | 49 | 34 | 29 | 58 | 60 | 54 | 40 | 27 | 56 | 54 | 48 | 40 | 31 | 48 | 37 | 26 | 39 | 38 |
| Tests on material passing No. 40 sieve: | | | | | | | | | | | | | | | | | | | | |
| Liquid limit | 17 | 17 | 18 | 16 | 18 | 18 | 17 | 16 | 15 | 16 | 17 | 14 | 14 | 13 | 10 | 14 | 15 | 27 | 25 | 25 |
| Plasticity index | 2 | 0 | 0 | 0 | 0 | 3 | 2 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |

[1] Dust ratio $=100\left[\frac{\text{percentage passing No. 200 sieve}}{\text{percentage passing No. 40 sieve}}\right]$.

In track 4, section 1 consisted of limestone, section 2 of granite, section 3 of blast-furnace slag, section 4, 90 percent by weight of granite and 10 percent slag, and section 5, 90 percent by weight of granite and 10 percent limestone.

Calcium chloride was used as an admixture in track 1 and sodium chloride in track 2. Track 3 was tested without a chemical admixture. Track 4 was tested first without chemical treatment and then with a surface application of calcium chloride.

In constructing the test sections of tracks 1, 2, and 3, sufficient water including that used to dissolve the chemicals was added to the aggregates to bring the mortar portion to its optimum moisture content as previously determined by the Proctor test (A. A. S. H. O. Standard Compaction Test No. T99–38) with a slight excess for wetting the coarse aggregate.

No Proctor compaction tests were made on the crusher-run materials used in track 4. Just enough water was combined with the mixtures used in this track to cause them to hold a cast when squeezed in the hand. Vibratory compaction [2] tests were made on these materials subsequent to the construction of the sections.

The moisture contents of all sections immediately after being placed in the track and the optimum moisture contents for the mortars of the materials used in tracks 1, 2, and 3, are shown in table 2.

The procedures for preparing the materials for the track tests, constructing the test sections, and surface-treating them were as follows:

1. Sufficient materials were prepared for only one track at a time. The aggregates were proportioned by weight from the stock materials to give the desired gradings and were thoroughly mixed before any water was added.
2. Water was added and mixing continued to distribute the moisture.
3. In tracks 1 and 2, the chemical admixture, in the amount of 2 pounds per square yard, was added as a solution along with the water.
4. The moistened mixtures were then placed in the trough of the track in two approximately equal layers, each layer being compacted with the traffic of pneumatic-tired wheels uniformly distributed over the surface.
5. Compaction was continued on the top layer until no further subsidence was noted and all sections were in suitable condition for testing. This required 18,200 wheel-trips, 64,000 wheel-trips, 60,000 wheel-trips, and 82,600 wheel-trips for tracks 1, 2, 3, and 4, respectively.

Table 2.—*Moisture contents immediately after construction and optimum moisture contents on the fraction of material passing the No. 10 sieve*

| Track No. | Section No. | Moisture content of sections after placing [1] | Optimum moisture content of material passing No. 10 sieve [2] |
|---|---|---|---|
| | | *Percent* | *Percent* |
| 1 | 1 | 8.6 | 9.8 |
| | 2 | 6.9 | 9.8 |
| | 3 | 7.0 | 8.6 |
| | 4 | 6.2 | 9.1 |
| | 5 | 6.9 | 9.0 |
| 2 | 1 | 7.1 | 10.0 |
| | 2 | 6.4 | 9.5 |
| | 3 | 6.6 | 9.5 |
| | 4 | 5.4 | 8.9 |
| | 5 | 4.3 | 8.6 |
| 3 | 1 | 6.9 | 10.0 |
| | 2 | 6.2 | 10.3 |
| | 3 | 5.3 | 9.7 |
| | 4 | 4.8 | 9.8 |
| | 5 | 4.3 | 9.1 |
| 4 | 1 | 6.7 | |
| | 2 | 10.0 | |
| | 3 | 8.0 | |
| | 4 | 9.6 | |
| | 5 | 11.2 | |

[1] Based on the dry weight of the total aggregate.
[2] Based on the dry weight of the portion of the aggregate passing the No. 10 sieve.

6. Testing of the materials without a bituminous surface treatment then proceeded.
7. After this phase of the testing had been completed, the sections were reshaped and trimmed smooth.
8. A prime consisting of 0.3 gallon per square yard of light tar was applied and allowed to cure.
9. A surface treatment consisting of 0.4 gallon of hot application bituminous material and a cover of 50 pounds per square yard of stone of ¾-inch maximum size was constructed.
10. The treatment was consolidated by additional distributed traffic until the surface was well sealed and showed no movement.

### WEATHER CONDITIONS VARIED CONSIDERABLY DURING TEST

The outdoor track was used in these investigations because it was desired to subject the materials treated with water-retentive chemicals to the influence of changes in temperature and humidity similar to those encountered on roads in service. A recording thermometer and hygrometer was installed near the track to determine these factors. A movable sheet metal roof, shown in figure 1, was used to cover the track at night and on rainy days so that the amount of water placed on the surface of each section could be accurately controlled.

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[2] A New Vibratory Machine for Determining the Compactibility of Aggregates, by J. T. Pauls and J. F. Goode, Public Roads, May 1939.

The tests described in this report were conducted at different times of the year. A brief summary of the temperature and humidity data collected by means of the recording instrument, previously mentioned, during the tests on the four tracks is presented in table 3.

The behavior of the materials under test was judged on the basis of the appearance of the sections at various stages of the tests supplemented by measurements of vertical displacement of the surface. The measurements were made with the transverse and longitudinal profilometers which have been described in the previous reports.

TABLE 3.—*Summary of weather data*

| | Track No. 1 | Track No. 2 | Track No. 3 | Track No. 4 |
|---|---|---|---|---|
| Date constructed | 7-15-36 | 10-19-36 | 4-12-37 | 10-8-37 |
| End of test | 10-12-36 | 4- 3-37 | 6-11-37 | 4-2-38 |
| Average daily maximum temperature ° F | 83.3 | 51.0 | 75.2 | 52.1 |
| Average daily minimum temperature ° F | 62.1 | 32.0 | 51.7 | 31.9 |
| Maximum recorded temperature ° F | 101 | 81 | 93 | 86 |
| Minimum recorded temperature ° F | 42 | 16 | 32 | 16 |
| Greatest change in 24 hours: | | | | |
| From ° F | 101 | 69 | 93 | 74 |
| To ° F | 67 | 31 | 42 | 29 |
| Average daily maximum relative humidity percent | 88.4 | 81.0 | 84.0 | 82.8 |
| Average daily minimum relative humidity percent | 35.8 | 31.0 | 26.0 | 39.1 |
| Maximum recorded relative humidity percent | 94 | 93 | 92 | 93 |
| Minimum recorded relative humidity percent | 14 | 9 | 9 | 6 |
| Greatest change in 24 hours: | | | | |
| From percent | 90 | 90 | 92 | 92 |
| To do | 14 | 10 | 9 | 8 |

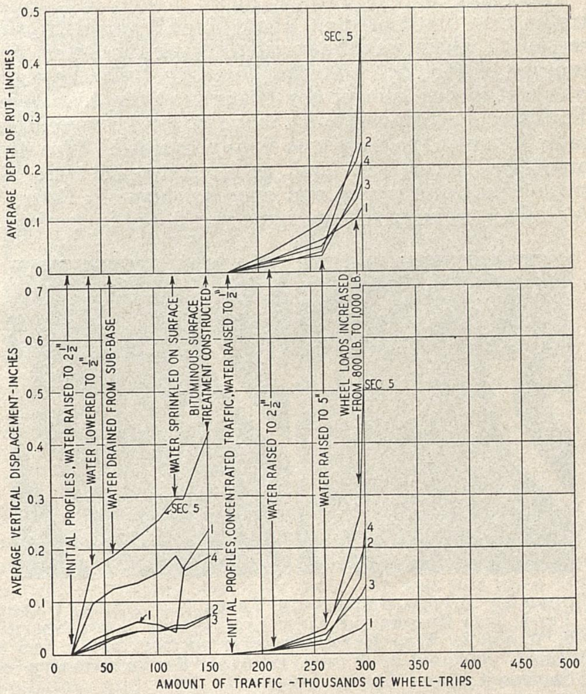

FIGURE 2.—SURFACE DISPLACEMENTS OF SECTIONS OF TRACK 1 AT VARIOUS STAGES OF THE TEST.

The resistance to raveling of the various materials when tested without the protective surface treatment was judged primarily by visual observation. No close correlation could be obtained between vertical displacement and the time raveling started because the concrete curbs prevented much of the loosened material from being thrown off the surface. During the portion of the test period in which water was sprinkled on the surface, increasing rates of vertical displacement were observed in some instances even though during this stage the surface was generally well bonded and in good condition.

An average vertical displacement of about 0.25 inch, measured after the sections had been surface treated and subjected to the action of concentrated traffic, was observed to be sufficient to cause noticeable damage to the bituminous surface. This is in agreement with conclusions reached in previous investigations using the same apparatus. Numerically, the amount of rutting measured with the longitudinal profilometer agreed in general with the amount of vertical displacement measured with the transverse profilometer.

Changes in behavior of the various sections under altered test conditions are clearly shown by abrupt changes in the slopes of the displacement curves in figure 2 for track 1 and in subsequent figures for tracks 2, 3, and 4.

*Track 1: Calcium chloride admixture.*—The schedule of traffic applications and changes in water elevation with notations on the behavior of the five test sections of track 1 are given in table 4.

Figure 2 shows the combined effect of consolidation and loss of surface material as measured by the transverse profilometer for the period up to 151,200 wheel-trips during which time the sections were being tested under distributed traffic, without bituminous surfaces. It also shows, for the period from 171,200 wheel-trips to the end of the test, the displacements of the sections as measured with both profilometers while testing under concentrated traffic, with bituminous surfaces.

TABLE 4.—*Schedule of operations and behavior of test sections in track 1 with calcium chloride*

| Operation | Traffic | Water level above top of sub-base | Behavior | | | | |
|---|---|---|---|---|---|---|---|
| | | | Sec. 1 | Sec. 2 | Sec. 3 | Sec. 4 | Sec. 5 |
| | *Wheel-trips* | *Inches* | | | | | |
| Placing and compacting | 0 to 18,200 | [1] 0 | Unstable | Good | Good | Good | Good. |
| Testing with distributed traffic | 18,200 to 38,200 | 2½ | Slightly unstable | do | do | do | Slight raveling. |
| Do | 38,200 to 58,200 | ½ | Good | do | do | do | Raveled. |
| Do | 58,200 to 118,200 | [1] 0 | do | do | do | Slight raveling | Do. |
| Sprinkling and testing with distributed traffic. | 118,200 to 151,200 | [1] 0 | Slightly unstable | do | do | Good during sprinkling, some raveling later. | Good during sprinkling, raveled later. |
| Compacting bituminous surface treatment. | 151,200 to 171,200 | [1] 0 | Good | do | do | Good | Good. |
| Testing with concentrated traffic | 171,200 to 211,200 | ½ | do | do | do | do | Do. |
| Do | 211,200 to 261,200 | 2½ | do | do | do | do | Do. |
| Do | [2] 261,200 to 298,500 | 5 | do | do | do | Slightly unstable | Unstable. |

[1] No water in sub-base.
[2] Wheel loads increased from 800 to 1,000 pounds at 295,000 wheel-trips.

Loosening of the surface metal under distributed traffic was first noted at about 35,000 wheel-trips in section 5, which was the section having the lowest percentage of No. 200 material. At this time the water was 2½ inches above the bottom of the test layer. Traffic was continued and the water level lowered (see table 4) until the base was finally drained. Raveling progressed in section 5 until, at 118,200 wheel-trips, the surface was quite loose and open as shown in figure 3. A similar action in lesser degree was noted in section 4.

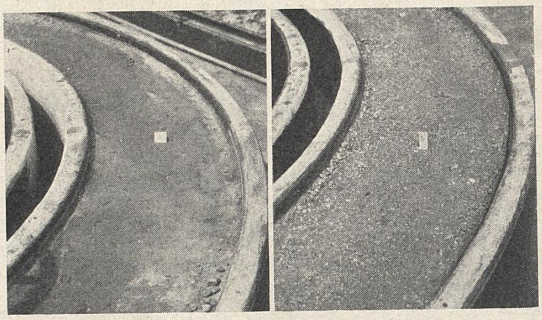

FIGURE 3.—TYPICAL SECTIONS OF TRACK 1 AT 118,200 WHEEL-TRIPS, JUST BEFORE THE FIRST SPRINKLING. LEFT, SECTION 2, WHICH IS ALSO REPRESENTATIVE OF SECTIONS 1 AND 3; RIGHT, SECTION 5, WHICH IS ALSO REPRESENTATIVE OF SECTION 4.

Sections 2 and 3 remained in good condition throughout this portion of the test. Section 1 failed to compact well during the initial compaction period (0 to 18,200 wheel-trips) but began to set up soon after water was admitted to the sub-base and exhibited no signs of excessive raveling from about 38,000 wheel-trips to 118,200 wheel-trips, when the track was first sprinkled. Figure 3 shows section 2 at 118,200 wheel-trips. Sections 1 and 3 were in a similar condition at this time. Some exposed aggregate was evident, particularly along the curb lines where abrasion was most severe, but in general the surfaces were dense and well bonded.

### LEACHING TESTS ON TRACK 1 STARTED AT 118,200 WHEEL-TRIPS

Water was applied to the surface of the test sections in track 1 during the traffic test period from 118,200 to 129,600 wheel-trips in the following manner:

1. Temporary dikes of plastic clay were placed at the ends of each section.
2. Water was sprinkled on the surface in increments equivalent to one-fourth inch of rainfall distributed over the area of each section.
3. The water was allowed to soak into the respective sections and to percolate through the test course, into the sub-base, and out the drains at the bottom.
4. After each of the first six applications of water had disappeared from the surface the dikes were removed and about 2,000 trips of test traffic applied.

Nine applications of water or the equivalent of 2¼ inches of rainfall were allowed to percolate down through the test course and six increments of traffic, 11,400 wheel-trips in all, were applied, bringing the total traffic to 129,600 wheel-trips.

The first application of water disappeared from the surface of section 5 in about 2 hours, and about 24 hours were required for the water to disappear completely from section 1. The time required for the water to enter the mixtures became progressively greater with each increment of water until toward the end of this phase of the test, 24 hours was required for section 5 to transmit a ¼-inch application of water.

Samples were taken from each section near the centerline just before the first application of water (118,200 wheel-trips) and again after the final application had leached through all sections. These samples were obtained by boring through the entire thickness of the test layer with a 1½-inch soil auger. Care was taken to save all the material from the test holes, which were made as nearly uniform in cross section throughout their depth as possible. The moisture content of each section as well as the calcium chloride content recovered from that portion of each boring passing the No. 10 sieve are shown in table 5 for the times indicated above as well as at the beginning and end of the test.

TABLE 5.—*Moisture contents and calcium chloride contents in track 1 at several stages of the test*

| Section No. | Number of wheel-trips | Stage of test | Moisture content based on dry weight | Calcium chloride content of portion passing No. 10 sieve |
|---|---|---|---|---|
| | | | *Percent* | *Percent* |
| 1 | 2,700 | Start | 8.6 | 0.22 |
| | 118,200 | Before sprinkling | 1.7 | 1.11 |
| | 129,600 | After sprinkling | 4.5 | .32 |
| | 298,500 | After testing with bituminous surface | 5.6 | .17 |
| 2 | 2,700 | Start | 6.9 | .19 |
| | 118,200 | Before sprinkling | 1.3 | .33 |
| | 129,600 | After sprinkling | 3.7 | .08 |
| | 298,500 | After testing with bituminous surface | 5.3 | .05 |
| 3 | 2,700 | Start | 7.0 | .22 |
| | 118,200 | Before sprinkling | 1.4 | .20 |
| | 129,600 | After sprinkling | 4.1 | .11 |
| | 298,500 | After testing with bituminous surface | 4.6 | .03 |
| 4 | 2,700 | Start | 6.2 | .26 |
| | 118,200 | Before sprinkling | 1.4 | .06 |
| | 129,600 | After sprinkling | 3.3 | .05 |
| | 298,500 | After testing with bituminous surface | 5.7 | 0 |
| 5 | 2,700 | Start | 6.9 | .27 |
| | 118,200 | Before sprinkling | 1.3 | .06 |
| | 129,600 | After sprinkling | 3.2 | .12 |
| | 298,500 | After testing with bituminous surface | 5.9 | 0 |

Tests on the mortar portion of the five mixtures just before laying showed calcium chloride contents of 0.19 to 0.27 percent of the dry weight of the fraction passing the No. 10 sieve. After 118,200 wheel-trips, the samples showed calcium chloride contents in the mortar portion of 1.11 percent for section 1, and 0.33 percent for section 2. The percentages of calcium chloride in the other sections at this time were less than at the start of the test, being 0.20 percent for section 3, and 0.06 percent for both sections 4 and 5.

Sections 1 and 2, which showed marked increases in chloride content along the center line, were denser and had higher dust contents than sections 3, 4, and 5. As will be shown later even greater increases were observed in sections 1 and 2 of track 2 in which sodium chloride was used as an admixture. There was nothing disclosed by the tests to explain these increases.

The effect of leaching on the chloride content is clearly shown in table 5. All sections except section 5 showed a decrease in the amount of the soluble salt present. Further decreases in chloride content were revealed by analyses made at the end of the test period. The retention of the admixture was greatest in section 1 which contained the clay-soil and decreased as the amount of material passing the No. 200 sieve decreased.

After the final application of water on the surfaces of the test sections, distributed traffic was continued to 151,200 wheel-trips with no water in the sub-base. During this period section 1, which had showed signs of surface rutting when saturated from the top, became stable again although the accumulated average vertical displacement had reached 0.24 inch before the surface treatment was applied. Sections 2 and 3 showed little movement and were not affected by the water applied to the surface. Sections 4 and 5 appeared to be benefited temporarily by the surface applications of water. Their surfaces became smooth and well bonded under the action of traffic. This improvement, although of very short duration, is shown by the temporary change in slope of their vertical displacement curves (fig. 2). As traffic was continued under drying conditions the previous tendency of these two sections to ravel reappeared. Figure 4 illustrates the appearance of typical sections of track 1 at 151,200 wheel-trips, or just before the bituminous surfaces were applied. The view of section 2 is representative of the condition of sections 1, 2, and 3. That of section 5 is representative of the condition of sections 4 and 5, and shows the decidedly loose and open-surface texture of these two sections.

### TRAFFIC TESTS CONTINUED AFTER BITUMINOUS SURFACE APPLIED

As shown in figure 2, new initial or zero displacement readings were taken after the application and compaction of the bituminous surface and the record from that time on or from 171,200 wheel-trips to the end of the test indicates the behavior of the chemically treated materials when acting solely as base courses.

The materials in all sections of track 1 gave good service and showed little movement as base courses even under the very severe test conditions imposed by maintaining the water elevation at 2½ inches. At 261,200 wheel-trips, or 90,000 wheel-trips after the start of concentrated traffic and 60,000 wheel-trips after the water had been raised to the 2½-inch level, the average vertical displacement of the surface on all the sections was less than 0.05 inch and the maximum amount of rutting was 0.09 inch. It was not until the water had been raised to the 5-inch level, or to within 1 inch of the bituminous surfacing, that pronounced base movement was observed. Under this extreme condition and with increased wheel loads, section 5 had definitely failed at the end of the test, 298,500 wheel-trips. Section 4 exhibited considerable movement and the surface treatment between the wheel courses was cracked. The wheel tracks were visible on sections 1, 2, and 3, but there was little distortion of the surface treatment. The condition of the track at the end of the test is shown in figure 5. The final condition of sections 2 and 3 was similar to that of section 1.

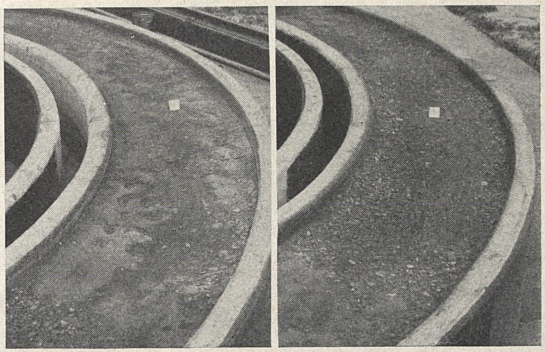

Figure 4.—Typical Sections of Track 1 at 151,200 Wheel-Trips, Just Before Construction of the Bituminous Surface. Left, Section 2, Which Is Also Representative of Sections 1 and 3; Right, Section 5, Which Is Also Representative of Section 4.

*Track 2: Sodium chloride admixture.*—This track consisted of five mixtures similar to those tested in track 1.

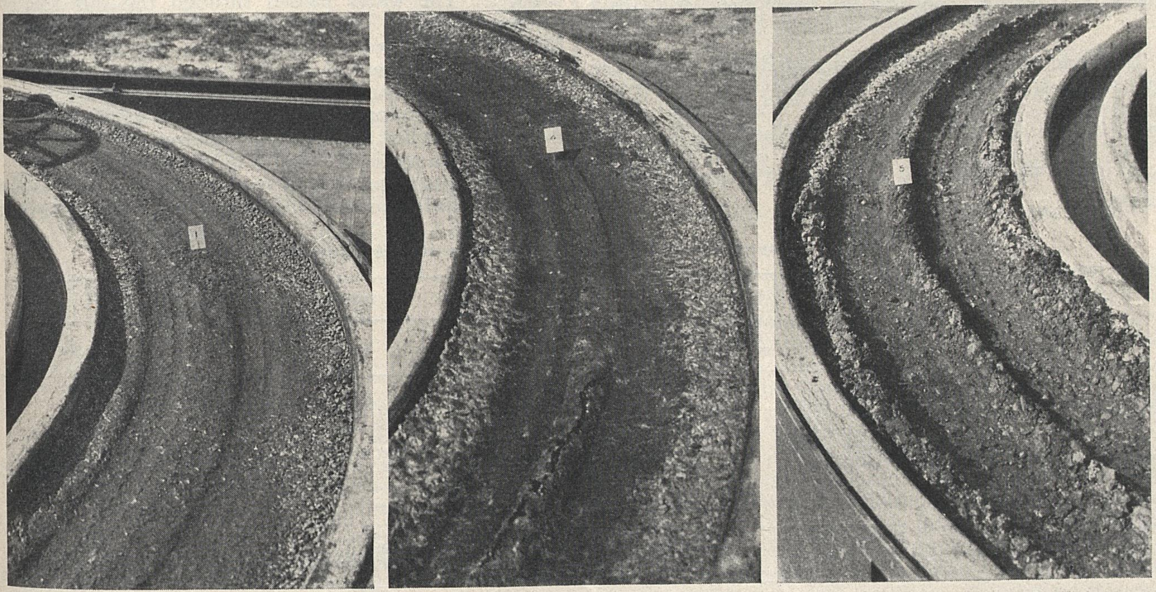

Figure 5.—Sections of Track 1 at the Conclusion of the Test. Left, Section 1, Which Is Also Representative of Sections 2 and 3; Middle, Section 4; Right, Section 5.

The test schedule together with notations on the behavior of the five test sections are given in table 6. Figure 6 shows the results of the displacement measurements.

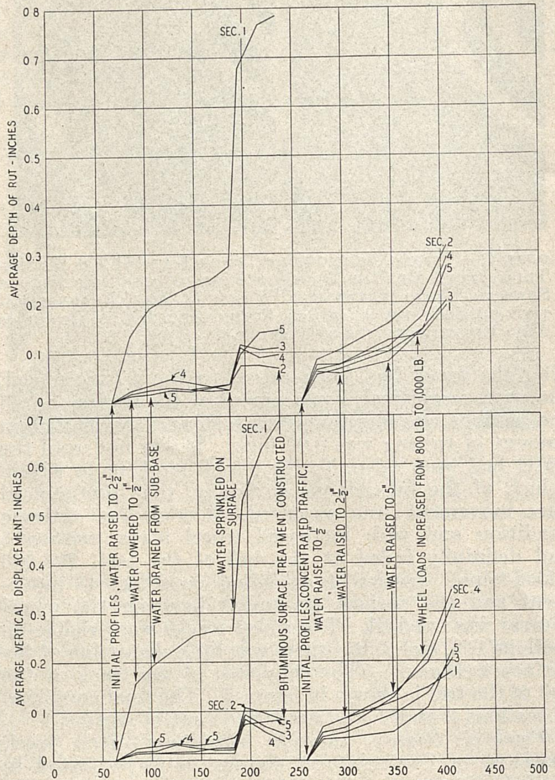

Figure 6.—Surface Displacements of Sections of Track 2 at Various Stages of the Test.

Raveling of the surface under distributed traffic was first noted at about 160,000 wheel-trips in section 5 and progressed gradually to 184,000 wheel-trips, when sprinkling was started. At this time sections 2, 3, and 4 had also started to ravel to some extent along the curb line. The condition of section 5 is illustrated in figure 7.

Figure 7.—Section 5 of Track 2 at 184,000 Wheel-Trips, Just Before the First Sprinkling. Some Raveling Had Developed, Particularly Along the Edges.

The average vertical displacement of sections 2, 3, 4, and 5 was less than 0.05 inch and the amount of rutting was correspondingly low. Section 1 of track 2 failed to compact readily as was the case with the corresponding section in track 1. In track 2, this section finally became stable at about 84,000 wheel-trips although the rate of average vertical displacement continued to be much higher than in the other sections up to about 150,000 wheel-trips. Thereafter little additional movement was noted until water was applied to the surface.

Sprinkling was started at 184,000 wheel-trips and continued in a manner similar to that described for track 1. The water passed through the salt treated sections slowly. The first application was made on a Saturday and had all disappeared by the following Monday. The second application required about 24 hours to disappear from section 5 and between 32 and 48 hours to disappear from the other sections. Four days after the last application there was still some water remaining on sections 1 and 2 in the low spots.

The moisture content of each section as well as the sodium chloride content determined on that portion of

Table 6.—*Schedule of operations and behavior of test sections in track 2 with sodium chloride*

| Operation | Traffic | Water level above top of sub-base | Behavior | | | | |
|---|---|---|---|---|---|---|---|
| | | | Sec. 1 | Sec. 2 | Sec. 3 | Sec. 4 | Sec. 5 |
| | *Wheel-trips* | *Inches* | | | | | |
| Placing and compacting | 0 to 64,000 | [1] 0 | Unstable | Good | Good | Good | Good. |
| Testing with distributed traffic | 64,000 to 84,000 | 2½ | Slightly unstable | do | do | do | Do. |
| Do | 84,000 to 104,000 | ½ | Slight pitting | do | do | do | Do. |
| Do | 104,000 to 184,000 | [1] 0 | Good | Slight raveling | Slight raveling | Slight raveling | Raveled. |
| Sprinkling and testing with distributed traffic. | 184,000 to 234,300 | [1] 0 | Slightly unstable | Good | Good | Good | Good during sprinkling but raveled later. |
| Compacting bituminous surface treatment. | 234,300 to 257,000 | [1] 0 | Good | do | do | do | Good. |
| Testing with concentrated traffic | 257,000 to 297,000 | ½ | do | do | do | do | Do. |
| Do | 297,000 to 347,000 | 2½ | do | do | do | do | Do. |
| Do | [2] 347,000 to 407,000 | 5 | do | Slightly unstable | Slightly unstable | Slightly unstable | Slightly unstable. |

[1] No water in sub-base.
[2] Wheel loads increased from 800 to 1,000 pounds at 375,000 wheel-trips.

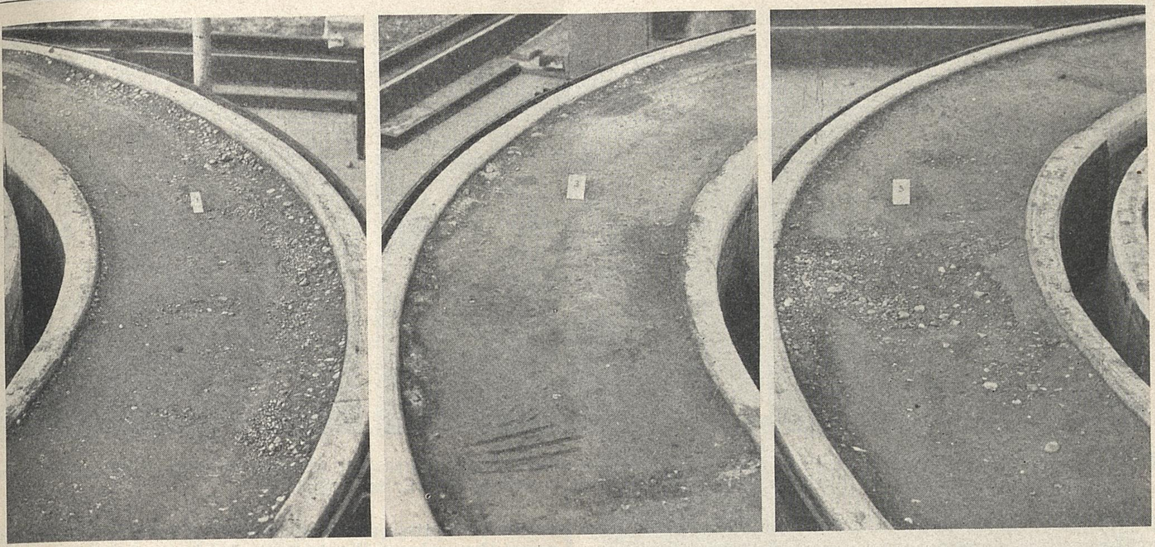

FIGURE 8.—SECTIONS OF TRACK 2 AT 234,300 WHEEL-TRIPS, JUST BEFORE CONSTRUCTION OF THE BITUMINOUS SURFACE. LEFT, SECTION 1; MIDDLE, SECTION 3, WHICH IS ALSO REPRESENTATIVE OF SECTIONS 2 AND 4; RIGHT SECTION 5.

the material passing the No. 10 sieve is shown in table 7 for various time during the testing period. The leaching effect is clearly illustrated in this table, being most pronounced in the sections with the lowest dust contents.

The sodium chloride contents of samples taken from sections 1, 2, and 5, were much greater at 184,000 wheel-trips than at the start of the track test. Section 3 showed a slight increase and section 4 a slight decrease

TABLE 7.—*Moisture contents and sodium chloride contents in track 2 at several stages of the test*

| Section No. | Number of wheel-trips | Stage of test | Moisture content based on dry weight | Sodium chloride content of portion passing No. 10 sieve |
|---|---|---|---|---|
| | | | *Percent* | *Percent* |
| 1 | 1, 600 | Start | 7. 1 | 0. 24 |
| | 184, 000 | Before sprinkling | 3. 6 | 1. 29 |
| | 196, 000 | After sprinkling | 5. 3 | . 21 |
| | 407, 000 | After testing with bituminous surface. | 5. 1 | . 16 |
| 2 | 1, 600 | Start | 6. 4 | . 31 |
| | 184, 000 | Before sprinkling | 3. 5 | 1. 49 |
| | 196, 000 | After sprinkling | 4. 6 | . 11 |
| | 407, 000 | After testing with bituminous surface. | 5. 5 | . 07 |
| 3 | 1, 600 | Start | 6. 6 | . 23 |
| | 184, 000 | Before sprinkling | 2. 7 | . 35 |
| | 196, 000 | After sprinkling | 3. 9 | . 06 |
| | 407, 000 | After testing with bituminous surface. | 4. 3 | . 03 |
| 4 | 1, 600 | Start | 5. 4 | . 27 |
| | 184, 000 | Before sprinkling | 2. 6 | . 19 |
| | 196, 000 | After sprinkling | 4. 4 | . 17 |
| | 407, 000 | After testing with bituminous surface. | 4. 7 | . 03 |
| 5 | 1, 600 | Start | 4. 3 | . 18 |
| | 184, 000 | Before sprinkling | 2. 3 | . 43 |
| | 196, 000 | After sprinkling | 3. 3 | . 04 |
| | 407, 000 | After testing with bituminous surface. | 5. 1 | . 02 |

Distributed traffic was continued after the final application of water on the surface up to 234,300 wheel-trips. All sections showed a marked increase in the rate of vertical displacement after the application of water. Section 1 softened on the surface but did not become unstable throughout its entire depth. The excessive displacements measured on section 1 (see fig. 6) may be explained by the fact that the softened surface crust picked up under the wheels and was either deposited on other sections or thrown off the track.

The photograph of section 1, figure 8, taken at 234,300 wheel-trips, shows this condition. It can be seen that the surface is definitely lower than that of the adjoining section shown in the background although there are no indications of rutting.

Sections 2, 3, and 4 showed an increase in vertical displacement during the sprinkling operations but bonded firmly under distributed traffic and actually became smoother as the test progressed up to 234,300 wheel-trips or the end of this phase of the test as illustrated by the view of section 3 in figure 8.

Section 5 continued to show increasing amounts of vertical displacement both during and after the sprinkling operation and while this section was not loose during the time water was being applied, evidence of raveling was noted as drying started soon after the last application. This section is also shown in figure 8.

### ALL MIXTURES IN TRACK 2 PROVED SATISFACTORY AS BASE COURSES

A bituminous surface treatment was applied to track 2 at 234,300 wheel-trips. All the mixtures proved satisfactory as base courses when treated with sodium chloride as they did in track 1 when treated with calcium chloride. Again it was necessary to raise the water table to the 5-inch level and increase the wheel loads to 1,000 pounds before definite indications of failure could be produced. The average vertical displacements and rutting (see fig. 6) varied from 0.04 to 0.09 inch for all sections between the time concentrated traffic was started at 257,000 wheel-trips and the time the second set of profiles was taken at 274,000 wheel-trips. Most of this displacement resulted from incomplete initial compaction of the surface treatment which was constructed in cold weather. Even with this displacement, which cannot be attributed to movement in the base, neither the average vertical displacements nor

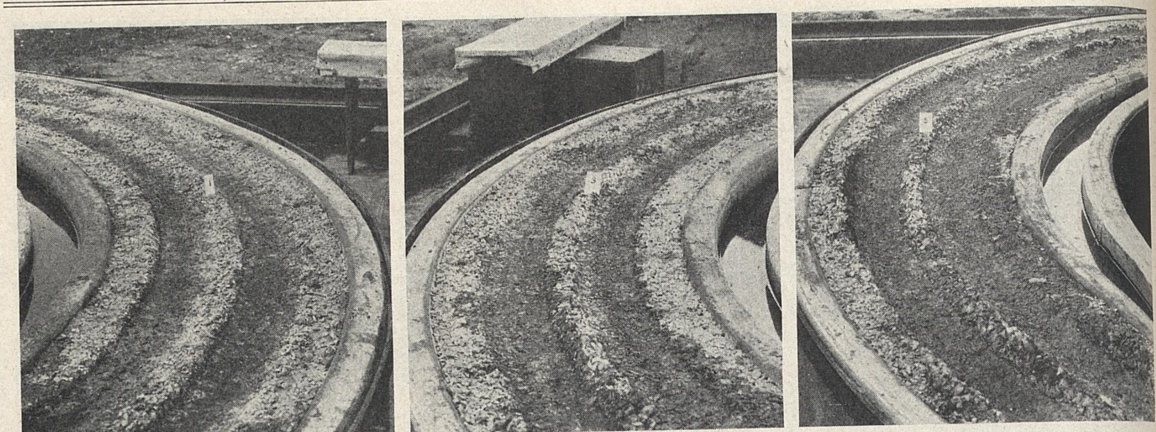

FIGURE 9.—SECTIONS OF TRACK 2 AT THE CONCLUSION OF THE TEST. LEFT, SECTION 1; MIDDLE, SECTION 3, WHICH IS ALSO REPRESENTATIVE OF SECTIONS 2 AND 4; RIGHT, SECTION 5.

the average depth of ruts exceeded 0.25 inch for any of the sections until near the end of the test.

When the test was concluded at 407,000 wheel-trips, section 1 was in fairly good condition except for the superficial rutting caused by poor compaction of the surface treatment (fig. 9), and showed the least amount of displacement. Profilometer measurements indicated the greatest amounts of movement to have occurred in sections 2 and 4. The appearance of these two sections at the end of test was very similar to that of section 3, shown in figure 9. The surface treatment on all three of these sections had cracked between the wheel courses. Section 5 was showing signs of failure at the end of the test although the total vertical displacement was not as great as for some of the other sections. The surface treatment was breaking and the section was becoming rough generally as shown in figure 9.

*Track 3: Without chemical admixture.*—Five mixtures similar in composition to those placed in tracks 1 and 2 were tested in track 3 without the admixture of a water-retentive chemical.

The schedule of testing operations and observations on the behavior of the five sections of track 3 are given in table 8. Figure 10 shows the average vertical displacement and the amount of rutting.

In general, the behavior of the five materials without chemical admixture was conspicuously different from that of the corresponding sections of tracks 1 and 2 prior to the application of the surface treatment. Section 1 failed to compact well, as did the same section in the two previous tracks, showing considerable movement throughout the 60,000 wheel-trips of compacting traffic. It differed widely from the others, however, during the initial flooding of the sub-base from 60,000 to 100,000 wheel-trips. (See table 8.) The surface became dry and dusty, indicating that evaporation was proceeding at a faster rate than the water could be brought up through the material by capillarity. No such behavior was observed in tracks 1 and 2 where water-retentive chemicals were used as admixtures.

Raveling in section 1 began shortly after 80,000 wheel-trips when the water was dropped to one-half inch above the bottom of the test course. Shortly before the sub-base was drained at 100,000 wheel-trips, sections 2 and 3 also started to ravel in the order named. The surfaces of all three sections were dry at this time in contrast to the surfaces of sections 4 and 5 which appeared damp and well bonded.

## SPRINKLING AIDED IN SURFACE MAINTENANCE OF GRANULAR MIXTURES

Upon the complete withdrawal of water from the sub-base, sections 4 and 5 also started to ravel. The condition of representative sections at 160,000 wheel-trips just prior to sprinkling is illustrated by figure 11. Section 1 is representative of the condition of both sections 1 and 2. Section 3 shown at the bottom of figure 11 was intermediate and sections 4 and 5 were in slightly better condition than section 3.

TABLE 8.—*Schedule of operations and behavior of test sections in track 3 without chemical admixtures*

| Operation | Traffic | Water level above top of sub-base | Behavior | | | | |
|---|---|---|---|---|---|---|---|
| | | | Sec. 1 | Sec. 2 | Sec. 3 | Sec. 4 | Sec. 5 |
| | *Wheel-trips* | *Inches* | | | | | |
| Placing and compacting | 0 to 60,000 | [1] 0 | Unstable | Slightly unstable | Good | Good | Good. |
| Testing with distributed traffic | 60,000 to 80,000 | 2½ | Dusty | Good | do | do | Do. |
| Do | 80,000 to 100,000 | ½ | Raveled | Raveled | Slight raveling | do | Do. |
| Do | 100,000 to 160,000 | [2] 0 | do.[3] | do.[3] | Raveled [3] | Raveled [3] | Raveled.[3] |
| Sprinkling and testing with distributed traffic. | 160,000 to 180,500 | [2] 0 | Good | Good | Good | Good | Good. |
| Compacting bituminous surface treatment | 180,500 to 200,500 | [2] 0 | do | do | do | do | Do. |
| Testing with concentrated traffic | 200,500 to 240,000 | ½ | do | do | do | do | Do. |
| Do | 240,000 to 260,000 | 2½ | do | do | Slightly unstable | do | Do. |
| Do | [4] 260,000 to 300,000 | 5 | do | do | Unstable | Unstable | Slightly unstable. |

[1] No water in sub-base. Water admitted to sub-base at 10,000 wheel-trips for 400 wheel-trips, then drained.
[2] No water in sub-base.
[3] Raveling was progressive from secs. 1 to 5.
[4] Wheel loads increased from 800 to 1,000 pounds, at 290,000 wheel-trips.

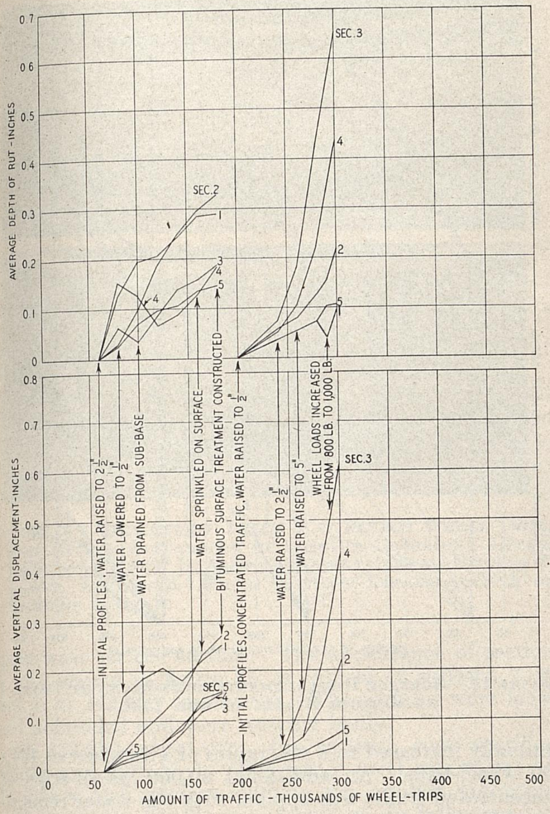

Figure 10.—Surface Displacements of Sections of Track 3 at Various Stages of the Test.

Sprinkling was started at 160,000 wheel-trips and continued in a manner similar to that described for tracks 1 and 2. The sections transmitted the water much more readily than did the corresponding sections treated with water-retentive chemicals.

All sections in track 3 were benefited by the application of water to the surface. Although the vertical displacements continued to increase (fig. 10) the surfaces became firm and the aggregates were well bonded under the action of traffic. Figure 12 shows the condition of sections 1 and 3 just prior to the construction of the bituminous surface at 180,500 wheel-trips. Comparison of the sections at this time with their condition as shown in figure 11 clearly illustrates the beneficial effect of the surface water.

A bituminous surface treatment was applied to track 3 at 180,500 wheel-trips. All five materials proved satisfactory as base courses without chemicals. The average vertical displacements and amounts of rutting (see fig. 10) indicated that detrimental movements were not produced until the water had been raised to the 5-inch level and the wheel loads increased to 1,000 pounds.

Sections 1 and 5 exhibited the least amount of movement when tested as base courses. They remained in excellent condition throughout this phase as illustrated in figure 13.

Section 2 moved more than sections 1 and 5 but was still in good condition at the end of the test. Some cracking of the surface treatment between the wheel courses was observed. The condition of these three sections was similar and is illustrated by the view of section 5, figure 13. Sections 3 and 4 showed sufficient rutting at the end of the test to indicate failure. However, this condition was produced only after unreasonably severe test conditions had been imposed. Section 3 in figure 13 is representative of the condition of both sections 3 and 4 at the conclusion of the test.

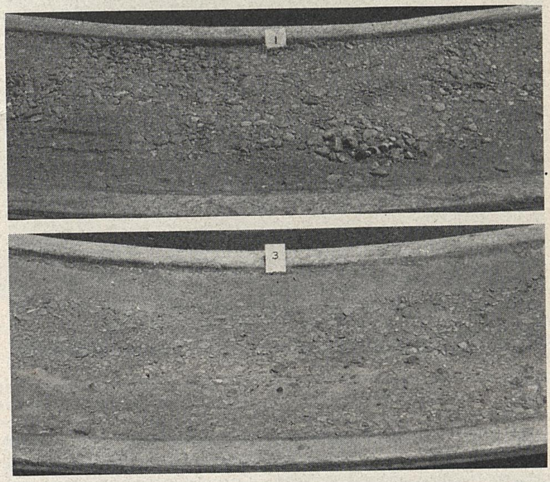

Figure 11.—Sections of Track 3 at 160,000 Wheel-Trips, Just Before the First Sprinkling. Upper, Section 1, Which Is Also Representative of Section 2; Lower, Section 3. Sections 4 and 5 Were in Slightly Better Condition Than Section 3.

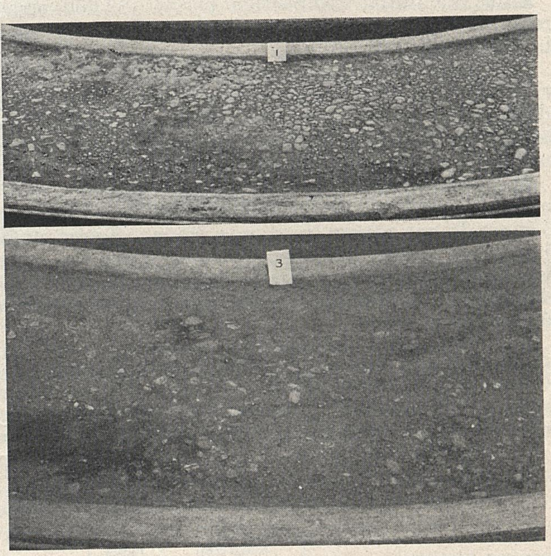

Figure 12.—Sections of Track 3 at 180,500 Wheel-Trips, Soon After Sprinkling Was Discontinued. Upper, Section 1, Which Is Also Representative of Section 2; Lower, Section 3, Which Is Also Representative of Sections 4 and 5.

*Track 4: Crusher-run materials.*—The five sections of track 4 were constructed of three types of crusher-run materials. Sections 1, 2, and 3 consisted of limestone, granite and slag materials, respectively, as obtained from commercial sources. Section 4 was a

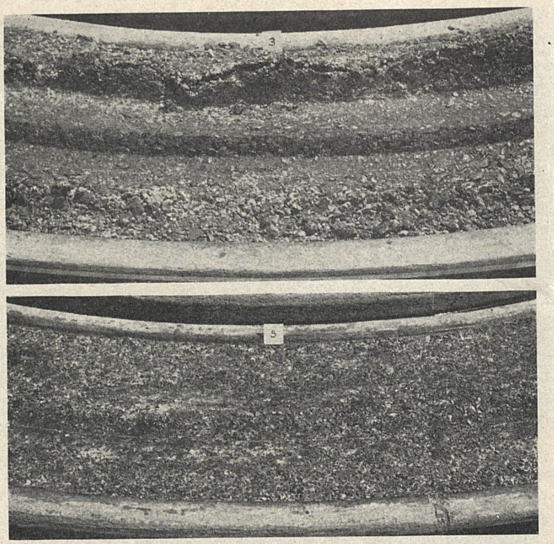

FIGURE 13.—SECTIONS OF TRACK 3 AT THE CONCLUSION OF THE TEST. UPPER, SECTION 3, WHICH IS ALSO REPRESENTATIVE OF SECTION 4; LOWER, SECTION 5, WHICH IS ALSO REPRESENTATIVE OF SECTIONS 1 AND 2.

mixture of 90 percent granite and 10 percent slag, and section 5 was a mixture of 90 percent granite and 10 percent limestone. The sections were constructed by dampening and compacting the materials without chemical admixtures.

After the initial compaction period (82,600 wheel-trips) the test was carried out in three distinct steps as shown in table 9.

1. The water level was raised to 2½ inches and distributed test traffic was applied from 82,600 to 182,600 wheel-trips while the water was gradually lowered and finally drained out of the sub-base. Distributed traffic was then continued to 242,600 wheel-trips.
2. The water was again raised to 2½ inches, and a surface application of calcium chloride at the rate of 1½ pounds per square yard was made. Testing with distributed traffic was then resumed while the water was again lowered and finally drained out at 308,800 wheel-trips. Distributed traffic was then continued to 366,000 wheel-trips.
3. A bituminous surface was constructed and concentrated traffic was applied while the water level was gradually increased to a maximum of 4½ inches at 474,300 wheel-trips. An additional 60,000 wheel-trips of concentrated traffic was applied with the water remaining at the 4½-inch elevation.

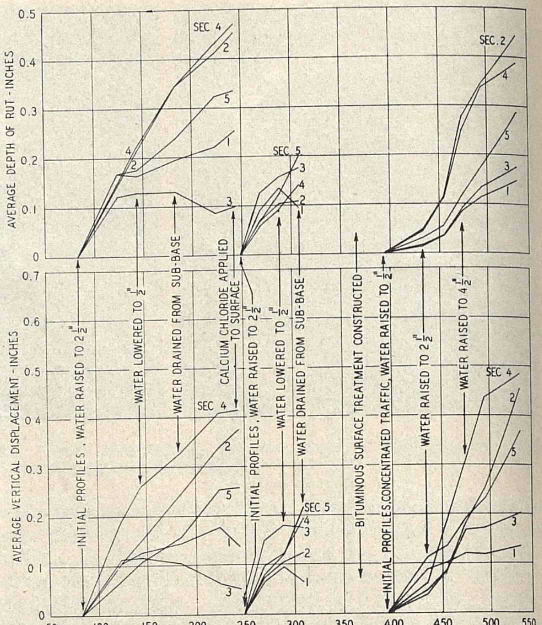

FIGURE 14.—SURFACE DISPLACEMENTS OF SECTIONS OF TRACK 4 AT VARIOUS STAGES OF THE TEST.

Sections 1 and 3 compacted well and showed no signs of raveling until the water had been completely withdrawn from the sub-base at 182,600 wheel-trips. Sections 2, 4, and 5 on the other hand did not bond or set up well. The surfaces of these sections became loose and dusty even with the water 2½ inches above the bottom of the test course.

Figure 14 shows the amounts of rutting and the average vertical displacements as measured by the profilometers. Both instruments indicated the greatest amount of movement up to 242,600 wheel-trips in sections 2 and 4 and the least movement in section 3. Section 1, figure 15, is representative of both sections 1 and 3. Slight raveling along the curbs was observed as well as

TABLE 9.—*Schedule of operations and behavior of test sections in track 4*

| Operation | Traffic | Water level above top of sub-base | Behavior | | | | |
|---|---|---|---|---|---|---|---|
| | | | Sec. 1 | Sec. 2 | Sec. 3 | Sec. 4 | Sec. 5 |
| | *Wheel-trips* | *Inches* | | | | | |
| Placing and compacting | 0 to 82,600 | [1] 0 | Good | Slightly unstable | Good | Slightly unstable | Unstable. |
| Testing with distributed traffic | 82,600 to 142,600 | 2½ | do | Raveled | do | Raveled | Raveled. |
| Do | 142,600 to 182,600 | ½ | do | do | do | do | Do. |
| Do | 182,600 to 242,600 | [1] 0 | Slight raveling | do | Slight raveling | do | Do. |
| Applying calcium chloride and compacting treated surface.[2] | 242,600 to 248,800 | [1] 0 | Good | Good | Good | Slightly unstable | Slightly unstable. |
| Testing with distributed traffic | 248,800 to 288,800 | 2½ | do | Slightly unstable | do | do | Unstable. |
| Do | [3] 288,800 to 308,800 | ½ | do | Unstable | do | Unstable | Do. |
| Do | 308,800 to 366,000 | [1] 0 | do | Slightly unstable | do | Slightly unstable | Do. |
| Compacting bituminous surface treatment. | 366,000 to 394,300 | [1] 0 | do | Good | do | Good | Good. |
| Testing with concentrated traffic | 394,300 to 434,300 | ½ | do | do | do | do | Do. |
| Do | 434,300 to 474,300 | 2½ | do | Unstable | do | Unstable | Slightly unstable. |
| Do | 474,300 to 534,300 | 4½ | do | do | do | do | Unstable |

[1] No water in sub-base.
[2] Sections scarified, sprinkled, compacted lightly, and treated with a surface application of 1½ pounds of calcium chloride per square yard.
[3] Section 5 scarified at 292,200 wheel-trips. Secs. 2, 4, and 5 scarified at 308,800 wheel-trips.

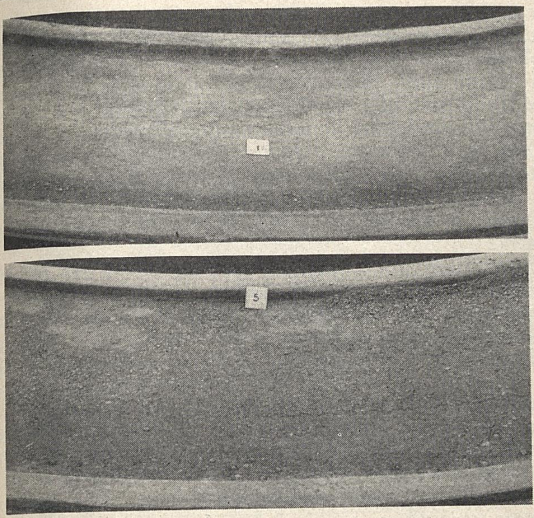

FIGURE 15.—SECTIONS OF TRACK 4 AT 242,600 WHEEL-TRIPS, JUST BEFORE APPLICATION OF CALCIUM CHLORIDE. UPPER, SECTION 1, WHICH IS ALSO REPRESENTATIVE OF SECTION 3; LOWER, SECTION 5, WHICH IS ALSO REPRESENTATIVE OF SECTIONS 2 AND 4.

some wear on the surface. The appearance of section 5, also shown in figure 15, is typical of sections 2, 4, and 5, at 242,600 wheel-trips. The surfaces were loose and unbonded and were wearing badly.

At 242,600 wheel-trips, the sections were scarified lightly and sprinkled. The water level was raised to 2½ inches and calcium chloride was applied uniformly to the surface. Traffic was started on the following day after all calcium chloride had disappeared from the surface.

No dusting or raveling was observed on any of the sections throughout the test period from the time calcium chloride was applied until the bituminous surface treatment was constructed.

The limestone and slag in sections 1 and 3, respectively, remained in good condition during this phase of the test as illustrated in figure 16. The other sections, which were constructed with granite as the predominating constituent, exhibited a marked movement of the surface. This was distinct from the raveling noted earlier in the tests and consisted of shoving and displacement in the direction of traffic. This is well illustrated in figure 16, which shows section 5. The condition described became so bad that it was necessary to scarify and reshape section 5 at 292,200 wheel-trips and sections 2, 4, and 5 at 308,800 wheel-trips.

At 366,000 wheel-trips, the sections were reshaped and compacted and the bituminous surface treatment was applied. Water was brought in contact with the base course and testing with concentrated traffic started at 394,300 wheel-trips.

Sections 1 and 3 remained in good condition throughout the test period. At the end of the test sections 2, 4, and 5, had definitely failed. The displacements for these latter sections were in excess of 0.25 inch and all three sections showed considerable movement under individual wheel-trips. As shown in figure 14 the displacement curves for these three materials rose continuously throughout the test. The displacement curves for sections 1 and 3 on the other hand flattened even under the extremely severe test conditions and never exceeded 0.2 inch. While sections 2, 4, and 5, gave evidence of fairly satisfactory service with the water elevation at one-half inch they appeared definitely inferior to sections 1 and 3 even at this stage of the test.

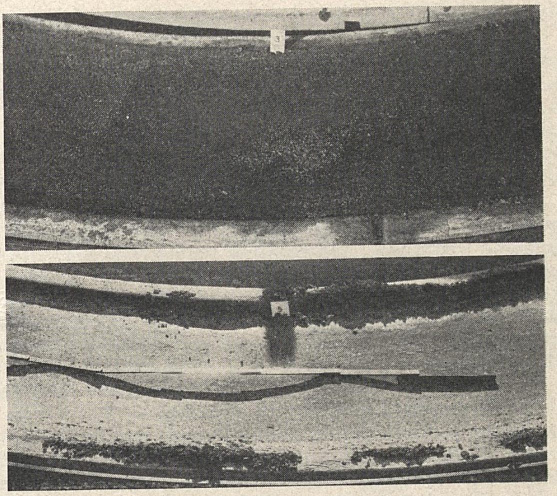

FIGURE 16.—SECTIONS OF TRACK 4 AT 366,000 WHEEL-TRIPS, JUST BEFORE CONSTRUCTION OF THE BITUMINOUS SURFACE. UPPER, SECTION 3, WHICH IS ALSO REPRESENTATIVE OF SECTION 1; LOWER, SECTION 5. SECTIONS 2 AND 4 WERE IN SOMEWHAT BETTER CONDITION THAN SECTION 5.

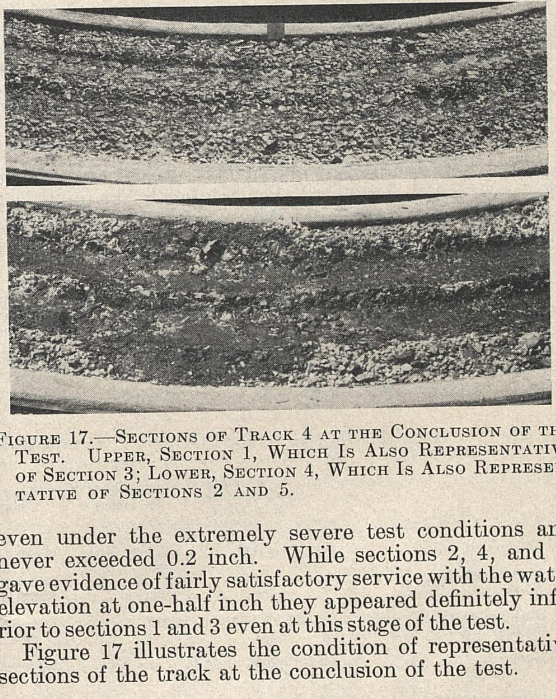

FIGURE 17.—SECTIONS OF TRACK 4 AT THE CONCLUSION OF THE TEST. UPPER, SECTION 1, WHICH IS ALSO REPRESENTATIVE OF SECTION 3; LOWER, SECTION 4, WHICH IS ALSO REPRESENTATIVE OF SECTIONS 2 AND 5.

Figure 17 illustrates the condition of representative sections of the track at the conclusion of the test.

### SUMMARY

The test behavior of all the sections in tracks 1, 2, and 3, is correlated in table 10.

*Performance as surfaces.*—The grading curves for the 5 materials tested in tracks 1, 2, and 3 are shown in figure 18. The shaded band in this figure is drawn to include the A. A. S. H. O. specification requirements for coarse-graded, aggregate-type surfacing materials. These specifications stipulate that the fraction passing the No. 40 sieve shall have a liquid limit not greater than 35 and a plasticity index not less than 4 nor more

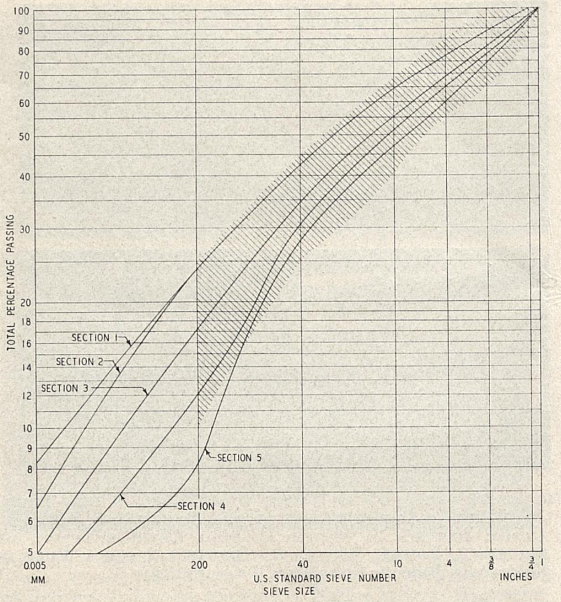

Figure 18.—Gradings of Materials in Tracks 1, 2, and 3. Shaded Area Indicates Zone Within Which Are Included the Specification Requirements of the A. A. S. H. O. for Type "B" Material for Stabilized Surface Course. Each Grading Curve Represents the Average Grading of the 3 Sections Having the Same Number Designation.

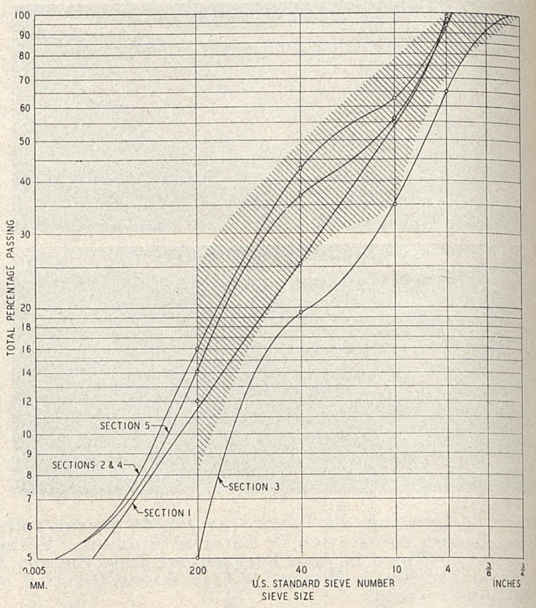

Figure 19.—Gradings of Materials in Track 4. Shaded Area Indicates Zone Within Which Are Included the Specification Requirements of the A. A. S. H. O. for Type "C" Material for Stabilized Surface Course.

than 9. The maximum plasticity index of any of the mixtures tested was 3 so that while all the mixtures except section 5 conform to the specifications in grading none of them has a plasticity index high enough to meet the specification requirements.

The tests with distributed traffic prior to surface treatment on track 3 without chemical admixture showed that these materials all raveled badly unless they were kept damp by capillary moisture from the ground water table or by water sprinkled on the surface. With decreasing ground water elevation, sections 1 and 2 with the greatest amount of material passing the No. 200 sieve raveled first. Further lowering of the ground water level produced raveling successively in sections 3, 4, and 5, which had dust ratios respectively of 48, 40, and 31. (See table 1.)

Table 10.—*Correlation of test behavior of the sections in tracks 1, 2, and 3*

| Track No. | Admixture | Sec. No. | Behavior under traffic | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Without bituminous surface | | | | | With bituminous surface | | |
| | | | Compacting without water in sub-base | Water level 2½ inches | Water level ½ inch | No water in sub-base just before sprinkling | After sprinkling and draining | Water level ½ inch | Water level 2½ inches | Water level 5 inches |
| 1 | Calcium chloride | 1 | Unstable | Slightly unstable. | Good | Good | Slightly unstable. | Good | Good | Good. |
| 2 | Sodium chloride | 1 | do | do | Slight pitting | do | do | do | do | Do. |
| 3 | None | 1 | do | Dusty | Raveled | Raveled | Good [1] | do | do | Do. |
| 1 | Calcium chloride | 2 | Good | Good | Good | Good | do | do | do | Do. |
| 2 | Sodium chloride | 2 | do | do | do | Slight raveling | do | do | do | Slightly unstable. |
| 3 | None | 2 | Slightly unstable. | do | Raveled | Raveled | do.[1] | do | do | Good. |
| 1 | Calcium chloride | 3 | Good | do | Good | Good | do | do | do | Do. |
| 2 | Sodium chloride | 3 | do | do | do | Slight raveling | do | do | do | Slightly unstable. |
| 3 | None | 3 | do | do | Slight raveling | Raveled | do.[1] | do | Slightly unstable. | Unstable. |
| 1 | Calcium chloride | 4 | do | do | Good | Slight raveling | Slight raveling | do | Good | Slightly unstable. |
| 2 | Sodium chloride | 4 | do | do | do | do | Good | do | do | Do. |
| 3 | None | 4 | do | do | do | Raveled | do.[1] | do | do | Unstable. |
| 1 | Calcium chloride | 5 | do | Slight raveling | Raveled | do | Raveled | do | do | Do. |
| 2 | Sodium chloride | 5 | do | Good | Good | do | Slight raveling | do | do | Slightly unstable. |
| 3 | None | 5 | do | do | do | do | Good [1] | do | do | Do. |

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[1] On track 3 traffic was discontinued 20,000 wheel-trips after sprinkling while the sections were still in good condition. Tests prior to sprinkling had indicated that 60,000 wheel-trips with water withdrawn from the sub-base would produce raveling in all sections.

The grading curves for the 5 materials tested in track 4 are shown in figure 19. The shaded band represents the A. A. S. H. O. specification limits for crusher-run surfacing materials. The slag tested in section 3 is coarser than provided for by the specifications. All other materials conform to the specification requirements. Sections 1 and 3, consisting of limestone and slag materials, were satisfactory throughout the tests and were definitely superior to sections 2, 4, and 5 which consisted of granite or largely of granite. The limestone and slag were naturally cementitious and bonded well in the test, whereas the pure granite which was used in section 2 failed to bond and was unstable under traffic. Admixtures of limestone or slag in the amount of 10 percent failed to improve to any appreciable extent the behavior of the crusher-run granite used in this investigation.

*Performance as base courses.*—The five materials tested in tracks 1, 2, and 3 gave good service as base courses except under the most severe testing conditions. The materials in sections 1, 2, and 3 were finer than the A. A. S. H. O. specification for base courses. The materials in sections 4 and 5, while conforming essentially to the specification, approached its fine limit. Previous investigations had shown that concentrated traffic, with the ground water elevation one-half inch above the bottom of the base course, provides a condition which is sufficiently severe to identify the definitely unsatisfactory materials. In these tests traffic was continued with increased wheel loading after the water had been raised to 5 inches above the bottom of the base course before evidences of failure were produced in tracks 1, 2, and 3.

At the conclusion of these very severe tests the following sections in tracks 1, 2, and 3 were in comparatively poor condition:

Track 1—sections 4 and 5.
Track 2—sections 2, 3, 4, and 5.
Track 3—sections 3 and 4.

In general, mixtures which had from 20 to 25 percent of material passing the No. 200 sieve proved more stable than those having lower dust contents. However, previous investigations[1] have shown that if the fines were plastic this amount of fine material would be detrimental.

The limestone and slag sections in track 4 gave good service as base courses under all conditions of the test. The granite sections exhibited increasing amounts of movement under traffic with the water one-half inch above the bottom of the base and failed under the severe conditions imposed toward the conclusion of the test.

Densities measured at the conclusion of the test on each track are shown in table 11. Densities obtained in the Proctor or A. A. S. H. O. standard compaction test are also shown in this table. The compaction tests were run on the soil mortar, or that fraction of the material passing the No. 10 sieve. The values shown in table 11 for tracks 1, 2, and 3, are corrected for the material retained on the No. 10 sieve.

With few exceptions, the densities measured in the track were less than the maximum densities computed from the Proctor compaction test. Section 1, which failed to compact readily early in the test in all three tracks, ultimately reached the highest density. Sections 4 and 5 which set up well initially, had densities considerably lower than the other sections in all tracks.

The densities attained in the track by the five crusher-run materials as compared with densities obtained in the vibratory compaction test (see table 12) gave no indication as to their suitability. Their behavior depended on other characteristics.

*Effect of chemical treatments.*—The effect of the chemical admixtures on the compactibility of the graded materials is shown by the behavior of the test sections during the initial compaction period. Track 1 which contained calcium chloride reached a condition considered suitable for starting the test at somewhat less than one-third the wheel-trips required to produce a similar condition in tracks 2 and 3.

Testing with distributed traffic prior to the construction of the bituminous surface treatment produced less raveling in sections 1, 2, and 3 in both tracks 1 and 2 in which a chemical admixture was used than in the corresponding sections of track 3 which contained no chemical. Section 4 of the chemically treated tracks

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[1] See footnote 1, p. 173.

TABLE 11.—*Moisture content and density of laboratory compacted aggregates and of circular track sections at conclusion of traffic test*

| Track No. | Admixture | Sec. No. | Compacted by Proctor method[1] | | | | Samples cut from track at end of test | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Water content based on dry weight | Composition by volume | | | Water content based on dry weight | Composition by volume | | |
| | | | | Water | Aggregate | Air voids | | Water | Aggregate | Air voids |
| | | | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| 1 | Calcium chloride | 1 | 6.1 | 13.9 | 86.1 | 0 | 5.6 | 12.8 | 86.0 | 1.2 |
| | | 2 | 6.8 | 15.1 | 84.0 | .9 | 5.3 | 11.8 | 84.3 | 3.9 |
| | | 3 | 4.9 | 11.3 | 87.4 | 1.3 | 4.6 | 10.5 | 85.8 | 3.7 |
| | | 4 | 5.4 | 12.4 | 86.6 | 1.0 | 5.7 | 12.4 | 82.0 | 5.6 |
| | | 5 | 4.7 | 10.8 | 86.5 | 2.7 | 5.9 | 12.8 | 81.7 | 5.5 |
| 2 | Sodium chloride | 1 | 6.5 | 14.7 | 85.3 | 0 | 5.1 | 11.8 | 87.3 | .9 |
| | | 2 | 6.1 | 13.7 | 84.9 | 1.4 | 5.5 | 12.4 | 84.9 | 2.7 |
| | | 3 | 5.3 | 12.2 | 87.0 | .8 | 4.3 | 9.8 | 86.3 | 3.9 |
| | | 4 | 4.5 | 10.5 | 88.4 | 1.1 | 4.7 | 10.3 | 82.8 | 6.9 |
| | | 5 | 4.0 | 9.4 | 88.4 | 2.2 | 5.1 | 10.9 | 80.6 | 8.5 |
| 3 | None | 1 | 6.6 | 14.8 | 84.9 | .3 | 5.3 | 12.0 | 85.5 | 2.5 |
| | | 2 | 6.1 | 13.9 | 86.0 | .1 | 5.2 | 11.6 | 84.2 | 4.2 |
| | | 3 | 4.7 | 11.1 | 88.8 | .1 | 4.8 | 10.5 | 82.7 | 6.8 |
| | | 4 | 4.9 | 11.5 | 88.5 | 0 | 4.9 | 10.7 | 82.6 | 6.7 |
| | | 5 | 4.2 | 9.7 | 87.6 | 2.7 | 5.2 | 11.1 | 80.6 | 8.3 |
| 4 | Calcium chloride[2] | 1 | | | | | 5.4 | 11.6 | 79.4 | 9.0 |
| | | 2 | | | | | 8.1 | 16.9 | 79.1 | 4.0 |
| | | 3 | | | | | 9.2 | 19.7 | 79.7 | .6 |
| | | 4 | | | | | 6.7 | 14.3 | 80.9 | 4.8 |
| | | 5 | | | | | 7.1 | 15.3 | 81.3 | 3.4 |

Compaction test made on portion passing No. 10 sieve and moisture contents and densities calculated for total mixture containing the coarse fraction.
[2] Surface application.

was only slightly better and section 5 no better than the corresponding sections of track 3. Sections 1 and 2 had the highest and section 5 the lowest dust contents.

In track 1, sections 4 and 5, which displayed the greatest amount of raveling, had calcium chloride contents of 0.06 percent when sampled at 118,200 wheel-trips or just before sprinkling. At the corresponding period of test on track 2, 184,000 wheel-trips, the sodium chloride content of section 4 was 0.19 percent and of section 5 was 0.43 percent. (See table 7.)

TABLE 12.—*Densities of crusher-run materials in track compared to densities obtained by vibration*

| Sec. No. | Density in track | Density obtained by vibration |
|---|---|---|
| | *Percent* | *Percent* |
| 1 | 79.4 | 84.0 |
| 2 | 79.1 | 79.2 |
| 3 | 79.7 | 77.9 |
| 4 | 80.9 | 79.4 |
| 5 | 81.3 | 80.1 |

The appearance just before sprinkling of section 5 in the two tracks containing admixtures is shown in figures 3 and 7, respectively. At the corresponding stage of the test, the condition of section 5 in track 3, which contained no admixture, was very similar to that of section 5 in track 1.

While water applied to the surface benefited all sections of track 3, it made section 1 of both the calcium chloride and sodium chloride treated tracks less stable. This loss of stability did not however, extend deeply into the course but was confined to the top inch.

The surface sprinkling failed to improve except temporarily the surface condition of the remaining sections of track 1, but had no detrimental effect on their stability. Aside from its detrimental effect on the surface of section 1, the sprinkling caused an improvement of considerable duration in track 2, which contained the sodium chloride (figs. 7 and 8). A shorter period of drying and less traffic were required to cause raveling to start again in both tracks after leaching than before.

In section 5 of track 1, the amount of raveling caused by only 25,000 wheel-trips subsequent to the surface application of water was decidedly greater than that produced by the 60,000 wheel-trips immediately preceding the sprinkling (figs. 3 and 4). Similarly, in section 5 of track 2, the 40,000 wheel-trips applied after sprinkling and prior to the construction of the bituminous surface treatment had a more detrimental effect than the 80,000 wheel-trips immediately preceding the first application of surface water (figs. 7 and 8).

The chloride content of all sections was reduced by the leaching action of the water sprinkled on the surface as indicated in tables 5 and 7. The calcium chloride content of the sections of track 1 varied from 0.05 percent for section 4 to 0.32 percent for section 1 after the leaching test. In track 2 the sodium chloride content varied from 0.04 percent for section 5 to 0.21 percent for section 1 after leaching.

Determinations at the conclusion of the track tests showed that, with the exception of section 3, the densities of corresponding sections in tracks 1, 2, and 3 were quite similar. In general the sections containing chemicals were slightly denser than the corresponding untreated sections and the densities were roughly proportional to the amount of material passing the No. 200 sieve. The greatest difference was in section 3. In tracks 1 and 2 the final densities of this section were 85.8 and 86.3 percent, respectively, as compared to 82.7 percent where no admixture was used.

## CONCLUSIONS

The following conclusions appear to be justified, for the sections considered as surface courses:

1. Nonplastic granular mixtures (tracks 1, 2, and 3) which have the grading requirements of the A. A. S. H. O. specifications for surfacing materials but lower plasticity indexes should give excellent service without chemical admixture when kept damp by capillary moisture or by water sprinkled on the surface. In permanently wet areas, therefore, it appears desirable to waive the minimum plasticity index requirement of 4 as required by the A. A. S. H. O. specification for surface courses, provided the nonplastic materials so admitted have dust ratios of 40 percent or less.

2. It was indicated that in dry locations and without chemical treatment the materials used in tracks 1, 2, and 3 would be subject to raveling and dusting if used as surfaces.

3. Crusher-run limestone and slag were satisfactory as surfacing courses under wet conditions but became dusty under dry conditions. The particular granite used in this investigation was not satisfactory as surfacing because it failed to bond or set up and because it shoved badly when wet.

4. Chemical treatments proved beneficial in the construction of bases for bituminous surfaces. The admixture of calcium chloride expedited compaction. Both calcium chloride and sodium chloride reduced raveling while the base courses were carrying traffic prior to construction of the bituminous wearing course. These results were obtained under conditions of high relative humidity.

5. The presence of 15 to 25 percent of material passing the No. 200 sieve is necessary to prevent the loss of a large part of the water-retentive chemicals when water falls on the surface and percolates through the mixture.

6. A surface application of calcium chloride was effective in reducing dusting and preventing raveling on all five sections in track 4. However, the moisture held near the surface of sections 2, 4, and 5 by the calcium chloride promoted the formation of corrugations to a detrimental extent.

For the sections considered as base courses, the following conclusions appear to be justified:

7. All materials tested in tracks 1, 2, and 3 both with and without chemical admixtures, gave excellent service as base courses except under moisture conditions much more severe than could reasonably be expected in service. It is believed therefore that existing surfaces which meet the A. A. S. H. O. surface course specifications for grading but which are nonplastic in character may be surface treated without altering their composition.

8. The limestone and slag sections of track 4 gave excellent results when tested as bases for bituminous surfacing under all conditions of moisture. Sections 2, 4, and 5, in which the crusher-run granite was the predominating constituent, were inferior to sections 1 and 3 but gave satisfactory service except under unreasonably severe test conditions.

9. Considerable latitude in grading requirements can be permitted when materials such as crusher-run limestone or slag are used for base courses. The natural cementing properties of these materials assist greatly in the formation of stable bases even when the grading is definitely coarser than would be allowed by the present A. A. S. H. O. specifications.

10. Materials that gave trouble during the early compaction period ultimately attained the highest density of any of the sections and gave satisfactory service. This confirms the conclusion reached in previous investigations that early difficulties encountered in compacting materials having acceptable gradings and plasticity indexes need not be taken as an indication of poor quality.

11. Because of its greater density and stability a well-graded sand-clay-gravel material having a low plasticity index is to be preferred to absolutely nonplastic material of comparable grading for base-course construction.

12. The tests indicate that properties other than those revealed by the mechanical analysis and plasticity tests influence the behavior of crushed stone or slag aggregates.

13. It is indicated that the crushed granite with the nonplastic binder used in these tests is not wholly satisfactory either as a surface or as a base. Since satisfactory roads have been built using granite from other sources a more comprehensive investigation of this class of material seems desirable.

# STATUS OF FEDERAL-AID HIGHWAY PROJECTS

## AS OF OCTOBER 31, 1939

| STATE | COMPLETED DURING CURRENT FISCAL YEAR | | | UNDER CONSTRUCTION | | | APPROVED FOR CONSTRUCTION | | | BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS |
|---|---|---|---|---|---|---|---|---|---|---|
| | Estimated Total Cost | Federal Aid | Miles | Estimated Total Cost | Federal Aid | Miles | Estimated Total Cost | Federal Aid | Miles | |
| Alabama | $ 1,740,986 | $ 864,785 | 100.6 | $ 7,917,594 | $ 3,892,318 | 259.9 | $ 520,090 | $ 259,040 | 10.2 | $ 2,724,845 |
| Arizona | 972,915 | 676,732 | 38.5 | 1,850,334 | 1,273,112 | 93.9 | 364,101 | 241,364 | 20.9 | 746,615 |
| Arkansas | 4,346,672 | 3,364,023 | 185.1 | 831,620 | 804,785 | 37.6 | 1,360,957 | 719,635 | 61.1 | 339,956 |
| California | 4,335,690 | 2,369,920 | 59.8 | 3,081,581 | 1,656,863 | 56.7 | 1,568,019 | 822,299 | 34.6 | 2,807,576 |
| Colorado | 1,665,527 | 918,250 | 41.4 | 3,311,197 | 1,844,183 | 77.8 | 366,428 | 206,519 | 7.8 | 1,636,253 |
| Connecticut | 357,558 | 176,334 | 5.1 | 1,964,755 | 977,627 | 19.9 | | | | 1,237,956 |
| Delaware | 516,499 | 252,872 | 12.0 | 1,278,959 | 626,818 | 26.4 | 181,020 | 90,510 | .1 | 1,019,316 |
| Florida | 121,000 | 59,928 | 1.4 | 4,284,214 | 2,141,882 | 72.9 | 505,649 | 252,825 | 7.9 | 2,500,855 |
| Georgia | 2,713,300 | 1,356,650 | 150.8 | 6,296,468 | 3,148,234 | 346.7 | 1,459,842 | 729,921 | 43.2 | 5,071,027 |
| Idaho | 1,658,103 | 999,180 | 82.6 | 1,155,908 | 703,715 | 64.6 | 274,979 | 154,602 | 27.0 | 1,055,403 |
| Illinois | 4,083,413 | 2,032,669 | 106.9 | 8,650,009 | 4,323,762 | 167.9 | 1,272,438 | 634,825 | 24.4 | 2,627,322 |
| Indiana | 2,115,702 | 1,057,851 | 38.6 | 6,069,452 | 3,010,126 | 135.3 | 732,436 | 366,143 | 13.7 | 1,865,082 |
| Iowa | 2,353,005 | 1,097,074 | 108.8 | 4,769,192 | 2,099,858 | 170.4 | 193,010 | 91,190 | 8.0 | 874,954 |
| Kansas | 2,375,055 | 1,179,822 | 130.8 | 2,398,403 | 1,198,322 | 115.4 | 2,915,692 | 1,457,846 | 148.1 | 4,043,296 |
| Kentucky | 1,428,269 | 714,135 | 48.7 | 3,668,742 | 1,832,815 | 94.4 | 915,801 | 457,900 | 23.1 | 2,696,361 |
| Louisiana | 318,148 | 156,000 | 10.8 | 12,132,849 | 3,115,133 | 49.7 | 1,518,979 | 742,323 | 45.1 | 2,361,588 |
| Maine | 1,813,070 | 906,176 | 42.1 | 1,031,510 | 515,755 | 24.8 | 90,670 | 45,335 | 2.7 | 287,017 |
| Maryland | 1,249,690 | 595,711 | 21.0 | 2,564,573 | 1,267,905 | 37.4 | 473,000 | 232,500 | 8.3 | 1,816,744 |
| Massachusetts | 3,107,045 | 1,550,834 | 25.1 | 713,333 | 355,469 | 4.5 | 1,258,822 | 627,124 | 7.5 | 2,486,225 |
| Michigan | 2,471,624 | 1,206,013 | 65.5 | 4,213,089 | 2,104,400 | 131.3 | 682,200 | 246,200 | 8.2 | 2,748,504 |
| Minnesota | 3,021,247 | 1,503,732 | 198.1 | 5,395,173 | 2,675,117 | 285.6 | 1,611,402 | 804,611 | 70.1 | 3,081,111 |
| Mississippi | 658,400 | 238,370 | 35.3 | 9,163,058 | 3,448,335 | 362.5 | 491,900 | 227,650 | 15.4 | 2,101,461 |
| Missouri | 1,452,003 | 725,302 | 55.9 | 5,105,064 | 2,518,032 | 180.7 | 2,742,221 | 1,138,414 | 93.0 | 3,889,219 |
| Montana | 1,670,146 | 944,760 | 111.4 | 2,159,501 | 1,221,799 | 86.3 | 1,770,551 | 1,004,254 | 113.9 | 3,485,875 |
| Nebraska | 1,159,765 | 574,441 | 76.1 | 6,126,753 | 3,062,728 | 571.0 | 2,045,743 | 877,990 | 202.8 | 2,509,368 |
| Nevada | 974,123 | 836,466 | 48.7 | 617,017 | 529,657 | 24.7 | 603,296 | 518,547 | 28.5 | 625,668 |
| New Hampshire | 539,946 | 264,083 | 18.1 | 949,318 | 467,479 | 21.3 | 228,372 | 113,783 | 9.1 | 881,230 |
| New Jersey | 400,110 | 191,531 | 3.6 | 4,409,098 | 2,202,999 | 34.4 | 180,660 | 90,330 | .1 | 1,835,924 |
| New Mexico | 1,290,907 | 795,998 | 108.3 | 980,780 | 598,068 | 38.6 | 496,131 | 309,635 | 38.6 | 1,128,560 |
| New York | 4,660,080 | 2,298,697 | 89.5 | 13,967,219 | 6,751,448 | 226.7 | 1,470,990 | 602,595 | 16.1 | 1,099,572 |
| North Carolina | 2,794,090 | 1,394,965 | 172.7 | 6,105,823 | 3,045,372 | 322.7 | 653,610 | 311,720 | 38.1 | 1,335,891 |
| North Dakota | 134,060 | 71,820 | 28.5 | 1,297,335 | 695,199 | 84.9 | 2,241,260 | 1,201,261 | 244.7 | 3,363,394 |
| Ohio | 2,702,668 | 1,351,334 | 32.5 | 9,116,948 | 4,489,760 | 98.0 | 3,140,160 | 1,450,580 | 27.9 | 5,709,230 |
| Oklahoma | 1,223,129 | 649,003 | 33.8 | 2,448,975 | 1,298,625 | 99.9 | 2,633,570 | 1,382,197 | 85.4 | 3,012,834 |
| Oregon | 1,687,139 | 1,005,727 | 89.1 | 2,432,864 | 1,455,960 | 85.2 | 1,276,854 | 600,150 | 36.4 | 1,039,348 |
| Pennsylvania | 4,601,129 | 2,283,475 | 63.0 | 8,677,516 | 4,168,217 | 76.6 | 3,025,417 | 1,500,078 | 37.3 | 3,147,258 |
| Rhode Island | 477,910 | 238,835 | 6.9 | 340,616 | 170,121 | 3.2 | 726,151 | 362,550 | 6.5 | 870,693 |
| South Carolina | 1,418,740 | 639,800 | 64.1 | 1,442,574 | 637,686 | 22.2 | 785,140 | 349,200 | 60.4 | 2,145,997 |
| South Dakota | 1,823,240 | 1,007,274 | 177.8 | 3,794,559 | 2,117,860 | 359.2 | 1,271,900 | 716,340 | 163.1 | 2,902,674 |
| Tennessee | 2,390,148 | 1,126,512 | 42.7 | 3,500,068 | 1,750,034 | 86.4 | 990,674 | 495,337 | 18.4 | 3,425,551 |
| Texas | 7,566,986 | 3,713,589 | 446.0 | 8,064,001 | 4,016,253 | 322.7 | 2,011,982 | 966,505 | 118.8 | 5,459,832 |
| Utah | 1,802,564 | 1,290,958 | 80.9 | 807,965 | 593,700 | 54.2 | 397,045 | 200,850 | 10.0 | 685,854 |
| Vermont | 708,655 | 347,793 | 17.8 | 209,404 | 104,512 | 5.5 | 631,844 | 315,900 | 20.9 | 301,224 |
| Virginia | 1,583,530 | 789,668 | 52.0 | 2,664,668 | 1,283,615 | 65.4 | 699,304 | 344,453 | 15.2 | 925,789 |
| Washington | 1,443,003 | 750,367 | 19.3 | 3,235,330 | 1,566,045 | 29.5 | 997,102 | 459,564 | 18.6 | 487,088 |
| West Virginia | 748,677 | 411,000 | 25.8 | 2,700,515 | 1,367,495 | 66.7 | 723,900 | 357,645 | 19.1 | 1,829,157 |
| Wisconsin | 3,845,993 | 1,887,062 | 140.3 | 6,096,440 | 2,998,880 | 188.6 | 393,586 | 185,145 | 14.6 | 1,637,742 |
| Wyoming | 1,204,864 | 752,152 | 118.0 | 689,717 | 422,277 | 75.3 | 713,328 | 450,147 | 66.3 | 563,935 |
| District of Columbia | | | | 341,624 | 170,812 | 2.1 | 106,700 | 53,350 | 1.0 | 263,338 |
| Hawaii | 139,841 | 66,868 | 1.0 | 993,980 | 480,750 | 16.4 | 579,027 | 286,093 | 10.1 | 1,055,906 |
| Puerto Rico | 647,050 | 322,600 | 13.8 | 1,282,253 | 635,060 | 24.9 | 83,226 | 40,975 | .6 | 376,160 |
| TOTALS | 94,513,414 | 50,009,141 | 3,646.6 | 193,299,938 | 93,836,977 | 5,908.9 | 52,377,179 | 26,095,950 | 2,102.9 | 102,123,778 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| District of Columbia<br>Hawaii<br>Puerto Rico | 139,841<br>647,050 | 66,868<br>322,600 | 1.0<br>13.8 | 993,980<br>1,282,253 | 480,750<br>635,060 | 16.4<br>24.9 | 579,027<br>83,226 | 286,093<br>40,975 | 10.1<br>.6 | 1,055,906<br>376,160 |
| TOTALS | 94,513,414 | 50,009,141 | 3,646.6 | 193,299,938 | 93,836,977 | 5,908.9 | 52,377,179 | 26,095,950 | 2,102.9 | 102,123,778 |

# STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

## AS OF OCTOBER 31, 1939

| STATE | COMPLETED DURING CURRENT FISCAL YEAR | | | UNDER CONSTRUCTION | | | APPROVED FOR CONSTRUCTION | | | BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS |
|---|---|---|---|---|---|---|---|---|---|---|
| | Estimated Total Cost | Federal Aid | Miles | Estimated Total Cost | Federal Aid | Miles | Estimated Total Cost | Federal Aid | Miles | |
| Alabama | $ 197,905 | $ 97,650 | 17.2 | $ 942,462 | $ 383,350 | 25.6 | $ 30,200 | $ 15,100 | 6.8 | $ 729,156 |
| Arizona | 150,487 | 108,529 | 16.5 | 147,395 | 105,786 | 16.9 | | | | 325,941 |
| Arkansas | 765,480 | 612,922 | 65.7 | 183,579 | 178,910 | 22.7 | 73,469 | 73,414 | 6.5 | 151,875 |
| California | 662,750 | 357,967 | 34.9 | 499,961 | 245,274 | 14.0 | 191,095 | 102,335 | 4.3 | 651,077 |
| Colorado | 518,727 | 265,180 | 19.5 | 478,290 | 269,039 | 14.0 | 36,596 | 20,626 | 3.1 | 31,948 |
| Connecticut | | | | 172,794 | 72,417 | 2.9 | 108,041 | 37,810 | .2 | 251,419 |
| Delaware | 80,840 | 40,420 | 17.5 | 71,661 | 35,831 | 7.8 | | | | 232,384 |
| Florida | 194,117 | 96,700 | 7.3 | 795,505 | 393,394 | 30.3 | 7,358 | 3,679 | | 371,271 |
| Georgia | 226,952 | 111,740 | 28.0 | 269,282 | 134,641 | 31.3 | 129,939 | 64,970 | 18.1 | 1,072,324 |
| Idaho | 214,675 | 129,195 | 22.9 | 319,386 | 163,267 | 25.8 | 130,982 | 70,634 | 9.3 | 73,778 |
| Illinois | 841,207 | 417,975 | 31.3 | 1,179,200 | 529,608 | 87.8 | 356,700 | 177,050 | 21.0 | 551,933 |
| Indiana | 489,000 | 244,500 | 41.7 | 714,596 | 356,094 | 54.3 | 112,122 | 56,050 | 9.4 | 631,614 |
| Iowa | 24,095 | 11,069 | 22.9 | 546,140 | 257,335 | 52.5 | 868,031 | 406,700 | 148.3 | 1,004,703 |
| Kansas | 56,428 | 28,214 | 26.1 | 183,802 | 91,901 | 20.5 | 340,325 | 170,161 | 7.3 | 1,291,203 |
| Kentucky | 445,912 | 143,463 | 44.0 | 1,057,612 | 299,582 | 54.3 | 521,864 | 181,918 | 49.8 | 223,613 |
| Louisiana | 471,353 | 215,553 | 41.5 | 348,970 | 166,888 | 27.0 | 358,993 | 166,352 | 29.0 | 283,778 |
| Maine | 324,403 | 162,130 | 18.6 | 161,120 | 79,474 | 9.4 | 19,700 | 9,850 | 1.2 | 9,072 |
| Maryland | 204,891 | 98,787 | 16.0 | 80,696 | 23,048 | 2.5 | 186,000 | 63,355 | 11.7 | 350,491 |
| Massachusetts | 101,519 | 50,435 | 2.4 | 507,052 | 251,158 | 11.1 | 49,200 | 24,525 | 1.6 | 463,550 |
| Michigan | 430,989 | 209,952 | 44.7 | 1,367,782 | 681,391 | 95.3 | 170,000 | 85,000 | 10.3 | 760,511 |
| Minnesota | 513,256 | 254,584 | 35.3 | 588,696 | 294,348 | 73.8 | 97,458 | 48,729 | 23.4 | 1,060,844 |
| Mississippi | 176,500 | 88,250 | 6.8 | 785,262 | 396,346 | 60.7 | 67,500 | 33,750 | 17.0 | 632,520 |
| Missouri | 645,117 | 311,688 | 96.0 | 720,758 | 342,330 | 67.3 | 138,612 | 52,437 | 25.8 | 561,273 |
| Montana | 468,607 | 265,790 | 48.6 | 381,003 | 216,037 | 23.0 | 59,718 | 33,872 | 6.6 | 816,329 |
| Nebraska | 464,642 | 222,306 | 88.3 | 823,370 | 404,510 | 144.7 | 139,699 | 69,850 | 25.4 | 319,657 |
| Nevada | 160,893 | 136,525 | 25.0 | 70,067 | 60,261 | 18.1 | | | | 145,070 |
| New Hampshire | 61,156 | 29,708 | 2.4 | 83,280 | 39,815 | 3.1 | | | | 150,441 |
| New Jersey | 255,320 | 125,610 | 7.1 | 295,020 | 146,820 | 17.3 | 24,500 | 12,250 | | 509,585 |
| New Mexico | 466,270 | 286,858 | 42.1 | 27,020 | 15,690 | | 361,210 | 146,391 | 26.9 | 80,519 |
| New York | 918,636 | 454,559 | 45.9 | 2,393,105 | 1,149,608 | 86.7 | 273,200 | 95,750 | 4.1 | 229,233 |
| North Carolina | 711,294 | 355,625 | 57.7 | 725,030 | 362,515 | 73.7 | 35,240 | 12,500 | 2.3 | 316,205 |
| North Dakota | 115,030 | 61,606 | 8.3 | 37,500 | 20,100 | | 111,270 | 59,617 | 10.9 | 819,207 |
| Ohio | 230,820 | 115,410 | 15.2 | 900,170 | 455,550 | 39.9 | 802,000 | 401,000 | 27.8 | 1,323,392 |
| Oklahoma | 81,838 | 38,943 | .8 | 336,696 | 179,153 | 16.8 | 470,655 | 250,428 | 36.9 | 858,921 |
| Oregon | 551,886 | 310,902 | 59.9 | 271,962 | 126,380 | 31.2 | 14,696 | 8,820 | | 292,800 |
| Pennsylvania | 1,905,307 | 940,977 | 109.3 | 1,096,322 | 542,056 | 38.5 | 370,074 | 185,037 | 13.3 | 211,879 |
| Rhode Island | 93,827 | 46,890 | 2.2 | 81,236 | 40,618 | .2 | 36,060 | 18,030 | .4 | 78,277 |
| South Carolina | 562,159 | 228,890 | 56.9 | 22,620 | 10,179 | | 303,500 | 126,600 | 22.2 | 220,251 |
| South Dakota | 3,830 | 2,100 | 4.0 | 23,396 | 12,878 | | | | | 1,043,072 |
| Tennessee | 732,508 | 313,954 | 27.1 | 226,796 | 113,398 | 5.3 | | | | 759,186 |
| Texas | 1,735,044 | 856,416 | 198.2 | 887,272 | 428,005 | 83.9 | 313,260 | 135,950 | 40.9 | 899,503 |
| Utah | 190,570 | 110,765 | 30.2 | 48,830 | 24,098 | 9.2 | 115,770 | 44,000 | 5.2 | 153,199 |
| Vermont | 126,051 | 62,026 | 4.5 | 187,872 | 61,587 | 7.3 | | | | 52,851 |
| Virginia | 525,334 | 255,171 | 57.3 | 232,980 | 114,854 | 14.4 | 310,590 | 136,228 | 17.9 | 172,598 |
| Washington | 473,395 | 247,383 | 26.0 | 290,290 | 151,918 | 22.9 | 103,829 | 53,400 | 11.2 | 215,301 |
| West Virginia | 145,150 | 72,575 | 8.3 | 13,015 | 6,507 | | 203,901 | 101,951 | 10.8 | 411,464 |
| Wisconsin | 523,087 | 260,059 | 27.1 | 591,300 | 295,162 | 9.3 | 471,585 | 221,418 | 7.3 | 473,606 |
| Wyoming | 464,992 | 288,144 | 26.0 | 159,218 | 100,513 | 10.3 | 112,112 | 65,156 | 19.6 | 64,172 |
| District of Columbia | 90,660 | 45,330 | 3.7 | 101,892 | 50,446 | 1.1 | 15,800 | 7,900 | .2 | 14,779 |
| Hawaii | | | | 205,590 | 102,795 | 4.6 | 179,480 | 89,705 | 6.4 | 82,170 |
| Puerto Rico | | | | 224,464 | 109,130 | 12.8 | 55,188 | 27,140 | 2.1 | 60,233 |
| TOTALS | 19,794,909 | 10,191,425 | 1,638.9 | 22,859,317 | 11,091,995 | 1,482.1 | 8,877,522 | 4,167,438 | 702.5 | 22,490,178 |

# STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF OCTOBER 31, 1939

| STATE | COMPLETED DURING CURRENT FISCAL YEAR | | | | | UNDER CONSTRUCTION | | | | | APPROVED FOR CONSTRUCTION | | | | | BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | NUMBER | | | | | NUMBER | | | | | NUMBER | | | |
| | Estimated Total Cost | Federal Aid | Grade Crossings Eliminated by Separation or Relocation | Grade Crossing Structures Reconstructed | Grade Crossings Protected by Signals or Otherwise | Estimated Total Cost | Federal Aid | Grade Crossings Eliminated by Separation or Relocation | Grade Crossing Structures Reconstructed | Grade Crossings Protected by Signals or Otherwise | Estimated Total Cost | Federal Aid | Grade Crossings Eliminated by Separation or Relocation | Grade Crossing Structures Reconstructed | Grade Crossings Protected by Signals or Otherwise | |
| Alabama | $ 515,350 | $ 503,059 | 5 | 1 | | $ 743,712 | $ 742,184 | 11 | | | $ 43,508 | $ 43,300 | 1 | 1 | 2 | $ 816,092 |
| Arizona | | | | | | 518,061 | 515,813 | 6 | | | | | | | | 209,120 |
| Arkansas | 189,891 | 189,891 | 3 | | | 669,853 | 663,348 | 3 | | | 23,968 | 23,968 | 2 | | 8 | 593,191 |
| California | 605,661 | 605,611 | 5 | | | 1,137,816 | 1,136,771 | 6 | | 1 | 137,560 | 137,560 | 2 | | 1 | 1,243,433 |
| Colorado | 309,307 | 309,305 | 3 | | 11 | 306,992 | 306,992 | 2 | | | 48,514 | 44,754 | | | 14 | 791,132 |
| Connecticut | | | | | | 172,722 | 161,008 | | 1 | | 21,333 | 21,333 | | | 7 | 829,223 |
| Delaware | | | | | | 9,150 | 9,150 | 2 | | | 2,320 | 2,320 | | | 1 | 513,891 |
| Florida | | | | | | 624,747 | 620,249 | 4 | | | 11,800 | 11,800 | | | 3 | 1,034,542 |
| Georgia | 56,530 | 56,530 | 3 | | | 405,396 | 405,396 | 4 | 1 | | 446,616 | 446,616 | 6 | 3 | 21 | 1,957,478 |
| Idaho | 191,612 | 160,443 | 3 | | | 122,880 | 122,518 | 1 | | | | | | | | 466,886 |
| Illinois | 1,846,535 | 1,845,675 | 11 | 3 | 43 | 1,828,339 | 1,689,967 | 10 | 1 | 21 | 184,242 | 173,570 | 3 | | 24 | 1,979,000 |
| Indiana | 739,703 | 739,703 | 3 | 1 | 45 | 398,555 | 398,555 | 1 | 1 | 33 | 423,614 | 423,614 | 1 | 1 | 52 | 740,558 |
| Iowa | 340,647 | 321,200 | 10 | | 2 | 279,344 | 242,456 | 4 | | 40 | 755,748 | 707,700 | 1 | | 180 | 831,318 |
| Kansas | 697,393 | 697,393 | 8 | | 4 | 655,704 | 655,704 | 7 | | 1 | 354,569 | 351,643 | 5 | | 7 | 778,718 |
| Kentucky | 380,015 | 380,015 | 6 | 4 | | 396,061 | 396,061 | 6 | | | 771,423 | 771,423 | 5 | | 13 | 375,135 |
| Louisiana | 122,838 | 122,830 | 2 | | | 824,494 | 770,989 | 7 | | | 317,665 | 317,659 | 10 | | | 584,469 |
| Maine | 327,109 | 327,109 | 3 | 2 | | 208,728 | 208,728 | 2 | 1 | | | | | | | 236,310 |
| Maryland | 24,510 | 15,402 | | | | 240,795 | 240,795 | 2 | | 2 | 46,200 | 46,200 | | | 13 | 925,099 |
| Massachusetts | 265,259 | 264,538 | 1 | 2 | | 257,307 | 256,764 | 3 | | | 14,320 | 14,320 | 1 | | | 1,711,447 |
| Michigan | 386,326 | 386,326 | 3 | 2 | 7 | 855,015 | 855,015 | 5 | | 3 | 475,081 | 475,081 | 3 | | 29 | 1,309,120 |
| Minnesota | 254,481 | 251,067 | 1 | 4 | 6 | 1,237,359 | 1,217,528 | 9 | 2 | 7 | 509,223 | 336,263 | 3 | | 6 | 1,117,339 |
| Mississippi | | | | | | 611,373 | 611,373 | 8 | | | 37,300 | 37,300 | 1 | | | 889,528 |
| Missouri | 65,589 | 64,284 | 1 | | | 1,266,356 | 1,266,356 | 7 | 2 | | 680,534 | 655,256 | 3 | 4 | | 1,324,064 |
| Montana | 614,653 | 614,653 | 6 | | | 448,927 | 333,846 | 6 | | | 80,000 | 80,000 | 1 | | | 204,589 |
| Nebraska | 381,275 | 380,675 | 13 | | | 781,157 | 781,157 | 12 | 1 | 2 | 269,075 | 269,075 | | 1 | 45 | 511,406 |
| Nevada | 156,993 | 156,993 | | 1 | 3 | 37,305 | 37,305 | | 1 | 5 | 11,577 | 11,577 | | | 5 | 114,944 |
| New Hampshire | 48,623 | 48,202 | 5 | | 1 | 113,962 | 113,879 | 3 | | | 45,804 | 45,804 | 2 | | | 313,600 |
| New Jersey | 7,140 | 7,140 | | | 1 | 730,316 | 730,316 | 2 | 3 | | 150,090 | 150,090 | 1 | | | 1,289,255 |
| New Mexico | 59,805 | 59,805 | 2 | | | 15,276 | 15,276 | | | | 2,572 | 2,572 | | | 1 | 692,665 |
| New York | 1,172,330 | 1,168,630 | 2 | 5 | | 2,360,212 | 2,182,492 | 10 | 9 | | 200,820 | 200,120 | 1 | 1 | | 3,453,396 |
| North Carolina | 668,844 | 636,144 | 4 | 2 | 18 | 876,400 | 874,000 | 9 | 3 | 8 | 444,735 | 444,735 | 2 | 1 | 39 | 586,364 |
| North Dakota | 105,450 | 105,450 | 3 | 1 | | 818,489 | 770,087 | 9 | | | 75,960 | 75,960 | 1 | | | 391,201 |
| Ohio | 308,640 | 293,640 | 6 | | | 1,449,673 | 1,378,721 | 8 | 3 | | 917,090 | 917,090 | 6 | | 4 | 2,473,570 |
| Oklahoma | 266,955 | 266,955 | 3 | | 32 | 187,025 | 187,025 | 3 | | 11 | 307,500 | 294,700 | 8 | 1 | 8 | 1,924,197 |
| Oregon | 40,500 | 39,002 | | | | 266,498 | 265,204 | 3 | | | | | | | | 311,060 |
| Pennsylvania | | | | | | 2,344,004 | 2,132,105 | 6 | 4 | | 520,652 | 312,200 | 2 | | 2 | 4,218,923 |
| Rhode Island | 327,613 | 327,613 | 1 | 2 | | 111,178 | 111,178 | | 1 | | | | | | | 152,459 |
| South Carolina | 177,614 | 144,232 | 4 | 2 | 7 | 590,456 | 568,120 | 6 | 3 | | 179,375 | 179,375 | | 2 | 26 | 782,723 |
| South Dakota | 72,757 | 72,757 | | 1 | 8 | 336,475 | 336,475 | 4 | 2 | 9 | 47,550 | 47,550 | 1 | | | 995,433 |
| Tennessee | 73,600 | 73,600 | | 1 | 1 | 799,806 | 799,806 | 3 | 3 | 2 | 6,760 | 6,760 | | | 2 | 1,332,344 |
| Texas | 1,204,696 | 1,173,640 | 12 | 2 | | 2,321,258 | 2,256,842 | 18 | 1 | | 51,150 | 51,150 | | | 26 | 1,913,207 |
| Utah | 111,841 | 111,778 | 2 | | 32 | 146,758 | 146,758 | 1 | | 53 | 161,010 | 161,010 | | | 58 | 177,522 |
| Vermont | 35,058 | 30,246 | | | 7 | 1,462 | 1,462 | | | | 118,940 | 118,940 | | 1 | | 200,249 |
| Virginia | 207,404 | 207,404 | 2 | | 16 | 515,975 | 423,075 | 7 | 2 | | 129,256 | 129,256 | 1 | 1 | 4 | 909,331 |
| Washington | 126,622 | 126,621 | 1 | | 8 | 209,590 | 208,180 | 2 | 1 | 2 | 208,720 | 208,037 | 1 | 2 | 2 | 362,668 |
| West Virginia | 64,417 | 64,417 | 2 | | | 310,434 | 294,674 | 5 | | | 24,200 | 24,200 | 1 | | 3 | 959,985 |
| Wisconsin | 480,877 | 478,594 | 6 | | 2 | 1,056,194 | 1,012,263 | 9 | 1 | 6 | 684,738 | 625,617 | 3 | 2 | 6 | 650,823 |
| Wyoming | 40,626 | 40,470 | 1 | | 7 | 98,543 | 98,543 | | 1 | | | | | | | 516,862 |
| District of Columbia | | | | | | 292,412 | 258,868 | 1 | | | 74,400 | 74,400 | | | | 47,053 |
| Hawaii | 52,950 | 50,320 | 1 | | | 132,850 | 132,850 | 3 | 1 | | 6,216 | 6,216 | | | 1 | 353,234 |
| Puerto Rico | 49,040 | 48,840 | 1 | | | 345,312 | 343,310 | 8 | | | | | | | | 426,676 |
| TOTALS | 14,175,079 | 13,968,202 | 148 | 36 | 261 | 31,468,706 | 30,287,537 | 248 | 49 | 206 | 10,023,728 | 9,478,114 | 78 | 21 | 613 | 47,522,832 |