# Deflections as an Indicator of Flexible Pavement Performance

F. P. NICHOLS, Jr., Highway Research Engineer, Virginia Council of Highway Investigation and Research, Charlottesville

•DEFLECTION MEASUREMENTS by means of the Benkelman beam have become increasingly important in evaluating the strength and load-carrying capacity of flexible pavements. The following report summarizes the results of tests performed in the spring of 1962 on 45 pavements in service in Virginia and of tests on 8 other pavements performed a year or two earlier. All but one of the 53 pavements reported were tested during the spring season, the period when subgrades are considered to be weakest. Also the paper presents a critical analysis of the effectiveness of certain commonly employed pavement design features in preventing excessive deflection and in improving performance.

An 18,000-lb single-axle load is employed in the measurement of deflections in Virginia. In the procedure now used, the rebound, or recovery from deflection, is measured rather than the deflection itself. At the start of the test, "the probe" (the tip of the lever arm) is inserted between the tires to a point exactly 2 ft ahead of the loaded wheel. The truck then moves forward slowly so that the maximum extensometer dial reading may be recorded as the load passes the point of measurement. Additional dial readings are made at intermediate points when the load is 2, 4, 6, and 9 ft beyond the probe. A final dial reading is taken after the test load has moved completely out of range of any possible effect on the measuring device. Figures 1 and 2 show the measurement procedure.

The value of total rebound deflection or recovery from deflection thus becomes the difference between the maximum dial reading and the final dial reading (multiplied by 2 to account for the mechanical advantage of the lever arm). The other values recorded are the differences between the dial readings when the load is at the various intermediate points, and the final dial reading when the load is out of range (again multiplied by 2). These values serve to define the approximate diameter of the "basin" deflected by the load, and indicate, in a qualitative sense at least, the degree to which the load is distributed to the underlying layers.

Using the preceding procedure, it is possible to make measurements in both wheelpaths at a great many sites in a single day. Test sites usually are spaced 50 ft apart in groups of five, thus covering a 200-ft length of highway per group. These groups are spaced at variable intervals, generally at least 1,000 ft apart; the number and spacing of groups on a given project are governed largely by the length of the project, by sight distances available to oncoming traffic, and by the frequency of superelevated curves. From 10 to 14 groups of test sites are established on a typical project and their locations are marked at the pavement edge with spray paint. Subsequent measurements on the same project are made at the exact same locations, insofar as it is possible to relocate the sites.

The familiar term, "deflection," still used frequently in the text, in all cases refers to the rebound value or recovery from deflection, determined in the manner just described.

## DEFLECTION TEST RESULTS

The data obtained from both the 1962 measurement program and those of prior years are summarized in tabular form in terms of total project averages and ranges in group averages. These tables also show structural thicknesses, construction costs,

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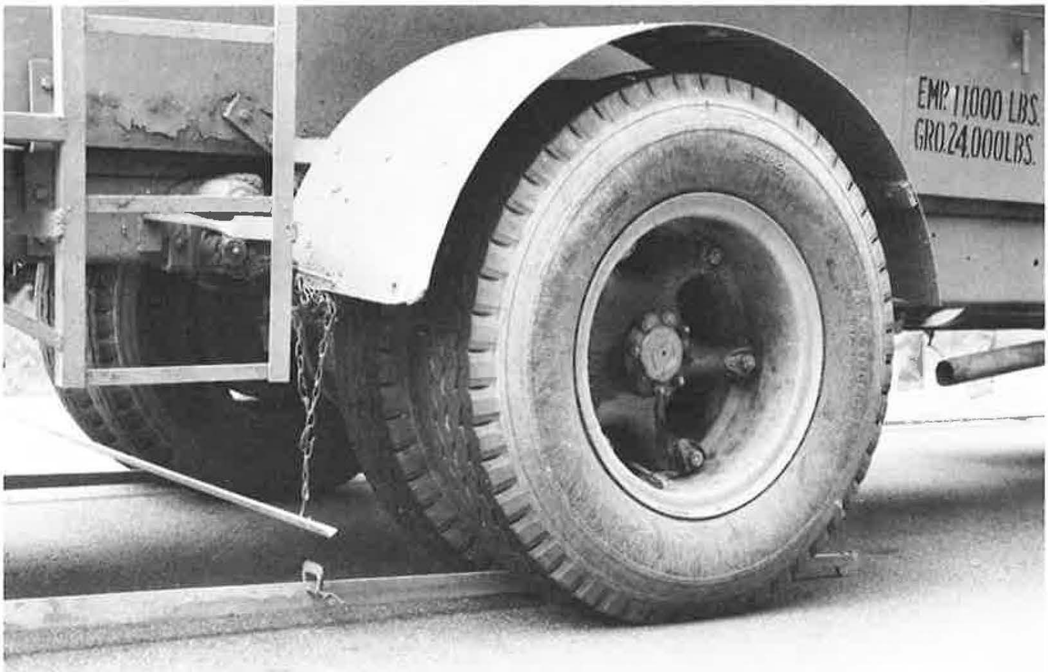


Figure 1. Test truck in initial position; points of measurement exactly 2 ft ahead of load wheels as indicated by clamps on beams.

the year the project was opened to traffic, and general remarks. The cost figures are discussed later.

Appendix A includes cross-section details for each project tested. Identification is provided by the code number corresponding to that shown in the first column of the tables.

In the "remarks" column is found first the average daily volume of trailer trucks and busses (TT & B) using the pavement in both directions, as reported in the Traffic and Planning Division's 1960-61 summary. Next is shown the soil area number, as defined in Appendix B. In general, these broad areas were numbered in the approximate order of suitability of the predominant soil types for highway subgrades, as seemed evident from analysis of condition survey data taken after the spring break up of 1948. Finally under "remarks" are found brief comments describing the performance of the pavement to date, including mention of average rebound deflection values which may have been determined in prior years.

Projects have been grouped for tabulation purposes in accordance with certain characteristics of their pavement designs such as the presence or absence of "black bases" or of lime or cement stabilization in either the subgrade or one of the structural components. Appendix C describes typical Virginia paving materials including the very popular black base mixes.

The first group of projects is distinguished by the inclusion in their designs of black bases, without any cement or lime stabilization in underlying layers. All the designs in this group include more than 6 in. total thickness of hot-mixed asphaltic concrete or sand asphalt. The essential data are summarized in Table 1.

The second group consists of pavements with untreated aggregate or water bound macadam bases and, again, no stabilization within the structure or in the subgrade. Though some of these have up to 3 in. of the H-3 (1) mix normally considered as "black base," the total thickness of asphaltic concrete is never as great as 6 in. The data for this group are summarized in Table 2.

Figure 2. Truck moving ahead and stopping with load wheels several feet ahead of point of measurement.

The third group consists of projects falling into the "black base" category (6 in. or greater total thickness of asphaltic concrete), but distinguished from those in the first group by the presence of a cement or lime stabilization of the subgrade. Data for this third group are given in Table 3. Total structural thicknesses include the stabilized subgrade layer, usually 6 in. thick. Only on project III-6 in this group was lime used.

Project average deflections in Table 3 are noticeably lower than most of those in Tables 1 and 2. Also the percent of deflection remaining as the load moves away is generally higher, indicating reduced bending of the surface layers and more favorable distribution of the load to the roadbed soil.

A fourth group is similar to the second in that the asphaltic concrete is less than 6 in. thick; it is similar to the third group in that the use of cement or lime stabilization of either subgrade or base is incorporated. Data for this group of projects may be found in Table 4. Even though some of these pavements were relatively inexpensive to construct, the effect of the cement or lime stabilization is indicated by the low deflections and good load distribution.

Still another listing is offered in Table 5 to summarize deflection data from the two experimental projects, one on Route 58 in Halifax County and the other on Route 360 in Charlotte and Prince Edward Counties. The variables on the first project have been described in other reports (1, 2) and are detailed again in the Appendix; essentially they are related to the thickness of asphaltic concrete in designs of the same total thickness, and no stabilization of subgrade or base is included. In the second project, comparisons

TABLE 1

FLEXIBLE PAVEMENT DEFLECTION SUMMARIES[a]

| When Project Tested | Code | Proj. No. | District | Date Tested | Temp. Range (°F) | Rebound Deflection (thousandths in.) OWP/IWP[b] Proj. Avg. | Range | % Defl. Remaining at Indicated Distance Average[b] 2 Ft | 6 Ft | 9 Ft | Structural Thickness (in.) A. C. | Total | Construction Costs ($/lin ft) Actual | Adjusted | Year Opened to Traffic | TT & B | Soil Area | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| In 1962 | I-1 | 0081-011 -001 | 2 | May | 55-60 | 13/13 | 11-17/11-16 | 31/23 | 8/0 | 0/0 | 9.5 | 24.5 | 16.09 | 18.31 | 1960 | 828 | 7 | Deflections measured in 1961 averaged 18/15, no defects noted. |
| | I-2 | 0029-071 -014-015 | 3 | May | 48-51 | 36/31 | 21-46/20-43 | 42/39 | 8/10 | 3/3 | 8.0 | 13.5 | 10.38 | 9.47 | 1955 | 269 | 11 | Cracking and rutting became pronounced until 1½" resurfacing applied in 1959; few cracks noted since. |
| | I-3 | 0029-071 -022 | 3 | May | 79-83 | 37/41 | 28-44/27-57 | 32/39 | 5/2 | 3/0 | 7.0 | 15.0 | - | 10.45 | 1958 | 234 | 11 | No defects noted. |
| | I-4 | 0029-071 -023-024 | 3 | May | 72-76 | 32/30 | 26-46/21-44 | 31/30 | 6/7 | 0/3 | 7.0 | 15.0 | - | 10.45 | 1958 | 234 | 11 | No defects noted. |
| | I-5 | 0058-041 -028-032 | 3 | March | 76-79 | 49/38 | 32-65/25-54 | 39/34 | 2/3 | 0/0 | 7.0 | 13.0 -37.0 | 10.51 -12.10 | 10.04 -16.01 | 1958 | 986 | 6 | Deflections measured in 1958 averaged 72/67. Cracking and rutting became pronounced until 1½" resurfacing applied in 1959. Few minor cracks again evident. |
| | I-6 | 0360-073 -002 | 3 | April | 64-68 | 25/20 | 14-39/12-27 | 56/45 | 4/5 | 0/0 | 9.0 | 15.0 | 9.55 | 11.89 | 1956 | 1,263 | 6 | A few odd cracks, apparently not caused by traffic. |
| | I-7 | 0360-073 -009-010 | 3 | April | 58-60 | 70/66 | 20-173/23-148 | 51/44 | 14/12 | 0/2 | 9.0 | 17.0 | 14.35 | 13.83 | 1958 | 1,263 | 6 | Badly cracked in places. Part resurfaced 1962. |
| | I-8 | 0060-020 -007 | 4 | April | 65-68 | 24/24 | 13-38/14-42 | 25/29 | 4/4 | 0/0 | 8.0 | 14.0 | 6.60 | 10.48 | 1956 | 190 | 2 | Edges cracked; OK otherwise. |
| | I-9 | 0095-074 -001 | 4 | April | 83-85 | 20/17 | 17-24/14-19 | 30/35 | 0/0 | 0/0 | 9.5 | 21.5 | 15.03 | 19.09 | 1961 | 1,328 | 1 | No defects noted. |
| | I-10 | 0301-074 -004 | 4 | April | 63-65 | 20/13 | 8-36/7-18 | 40/46 | 5/0 | 0/0 | 7.0 | 13.0 | 5.23 | 9.38 | 1956 | 1,328 | 1 | Slippage cracks on original surface followed by general transverse cracking necessitated two complete resurfacings by 1960, total 3". Transverse cracking still evident. |
| | I-11 | 0360-020 -013 | 4 | May | 85-88 | 62/58 | 27-124/30-98 | 21/34 | 2/4 | 0/2 | 9.0 | 15.0 | 8.44 | 10.91 | 1954 | 1,036 | 2 | Pronounced cracking general except where resurfaced in 1961. |
| | I-12 | 0360-020 -019-027 | 4 | April | 83-85 | 42/38 | 26-67/21-60 | 26/26 | 5/5 | 0/0 | 9.0 | 15.0 | 10.39 | 11.38 | 1956 | 1,123 | 3 | Occasional pronounced cracking noted. |
| | I-13 | 0017-030 -010 | 7 | May | 92-96 | 46/39 | 24-60/26-63 | 22/26 | 0/3 | 0/0 | 7.0 | 16.0 -22.0 | 11.86 | 12.82 | 1957 | 122 | 6 | Cracking and rutting became pronounced until 1½" resurfacing applied in 1961. |
| | I-14 | 0029-023 -005 | 7 | May | 83-87 | 62/52 | 40-81/30-71 | 16/19 | 2/2 | 0/0 | 7.0 | 13.0 | 11.62 | 10.21 | 1959 | 319 | 11 | Cracking and rutting became pronounced until 1½" resurfacing applied in 1961. Minor cracks again noted. |
| | I-15 | 0029-030 -002 | 7 | May | 73-76 | 40/35 | 29-48/25-40 | 30/34 | 2/3 | 0/0 | 9.0 | 12.0 | 9.54 | 10.62 | 1955 | 435 | 11 | Part resurfaced in 1961. Balance generally cracked, some pronounced. Little effect on deflections noted from resurfacing. |
| Before 1962 | I-16 | 0081-077 -001 | 2 | Oct. 60 | 65-83 | 19/19 | 11-26/12-25 | 28/28 | 4/3 | 0/0 | 9.5 | 24.5 | 16.68 | 21.53 | 1960 | 1,119 | 7 | No defects noted. |
| | I-17 | 0081-077 -008 | 2 | Oct. 60 | 65-83 | 24/22 | 19-30/16-31 | 24/25 | 4/2 | 0/1 | 9.5 | 24.5 | 19.86 | 21.53 | 1960 | 1,119 | 7 | No defects noted. |
| | I-18 | 0301-048 -002 | 6 | March 1961 | 50-58 | 9/10 | 5-13/6-13 | 73/60 | 15/10 | 3/1 | 8.5 | 16.5 -18.5 | 5.52 | 8.00 -8.29 | 1951 | 984 | 1 | Remarkable performance; practically no defects after 11 winters. |
| | I-19 | 0081-082 -021 | 8 | Apr. 60 | 63-75 | 13/12 | 6-19/7-18 | 42/- | 4/- | 0/- | 9.5 | 27.5 | 16.67 | 21.11 | 1960 | 907 | 7 | No defects noted. |
| | I-20 | 0081-082 -017 | 8 | Apr. 60 | 63-75 | 22/22 | 17-22/11-25 | 37/- | 4/- | 0/- | 9.5 | 27.5 | 17.88 | 21.11 | 1960 | 956 | 7 | No defects noted. |

[a] Black bases—no stabilization in subgrade or subbase.

[b] Figures to left of slash for outer wheelpath, to right for inner.

TABLE 2

FLEXIBLE PAVEMENT DEFLECTION SUMMARIES[a]

| Code | Project No. | District | Date Tested | Temp. Range (° F) | Rebound Deflection (thousandths in.) OWP/IWP[b] | | % Defl. Remaining at Indicated Distance Average[b] | | | Structural Thickness (in.) | | Construction Costs ($/lin ft) | | Year Opened to Traffic | TT & B | Soil Area | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Proj. Avg. | Range | 2 Ft | 6 Ft | 9 Ft | A. C. | Total | Actual | Adjusted | | | | |
| II-1 | 0460-035 -012 | 2 | May 1962 | 60-63 | 24/25 | 14-38/16-35 | 25/24 | 4/4 | 0/0 | 1.0 (M. I. P.) | 13.0 | 5.52 | 6.21 | 1956 | 29 | 7 | Deflections measured in August 1959 averaged 25/21; in May 1960, 26/30. General surface deterioration until 1½" resurfacing applied in 1960. No defects since. |
| II-2 | 0058-041 -014 | 3 | April 1962 | 46-52 | 52/42 | 20-78/16-63 | 37/26 | 4/2 | 0/0 | 2.0 | 37.0 | 8.88 | 9.84 | 1956 | 986 | 6 | Deflections measured in 1957 averaged 37/35; in 1958, 56/47. General pronounced cracking in both lanes. Has been resurfaced since 1962 tests made. |
| II-3 | 0058-041 -015 | 3 | March 1962 | 45-80 | 48/37 | 16-69/14-62 | 35/35 | 4/5 | 0/0 | 2.5 | 14.5 -30.5 | 9.08 -9.75 | 9.72 -11.96 | 1957 | 986 | 6 | Deflections measured in 1957 averaged 65/62; in 1958, 52/49. Pronounced alligator cracking over most of project soon after completion; 1½" resurfacing applied in 1957. Considerable cracking has reappeared but riding quality not impaired appreciably. |
| II-4 | 0017-030 -015 | 7 | May 1962 | 60-65 | 60/61 | 32-111/24-92 | 17/24 | 2/2 | 0/0 | 4.5 | 23.5 -29.5 | 11.58 -12.55 | 11.57 -13.03 | 1958 | 122 | 6 | General minor alligator cracking, occasionally pronounced. Some rutting. |
| II-5 | 0020-068 -010-013 | 7 | May 1962 | 68-70 | 35/33 | 27-50/25-48 | 31/33 | 6/6 | 3/3 | 1.0 (M. I. P.) | 13.0 | 6.52 | 5.31 | 1957 | 60 | 6 | General pronounced surface distress after first winter. 1½" resurfacing applied in 1958. Many patches and areas of pronounced cracking again evident. |
| II-6 | 0020-068 -101, C-501 | 7 | May 1962 | 84-87 | 38/35 | 21-76/14-68 | 45/40 | 5/6 | 3/3 | 4.0 | 12.0 — + | -- | 10.61 | 1962 | 60 | 6 | New project. No defects. |
| II-7 | 0029-056 -102, C-1 | 7 | May 1962 | 90-92 | 53/47 | 31-68/28-66 | 23/23 | 4/4 | 2/2 | 4.5 | 24.5 -48.5 | 8.92 -10.26 | 8.73 -17.07 | 1961 | 352 | 6 | Deflections measured in 1961 averaged 44/41. General minor alligator cracking, some surface ravelling; spotty texture. |
| II-8 | 0017-030 -002 | 7 | May 1962 | 88-91 | 44/44 | 24-64/22-65 | 32/32 | 5/2 | 2/0 | 2.0 | 11.0 -27.0 | 7.18 -8.59 | 6.85 -8.29 | 1952 | 271 | 6 | Surface cracking became pronounced until 1½" resurfacing applied in 1958. Cracks reappeared until seal applied in 1961. |
| II-9 | 0029-076 -007;-030-001 | 7 | May 1962 | 67-70 | 26/20 | 21-31/15-32 | 19/25 | 4/5 | 0/0 | 3.0 (Pen. Mac.) | 13.0 -27.0 | 8.47 -9.57 | 8.21 -10.93 | 1953 | 435 | 11 | Original M. I. P. surface developed minor cracking and raveling until 1½" resurfacing applied in 1958. Few defects since. |

[a]Untreated aggregate or water-bound macadam bases; no stabilization in subgrade or subbases.
[b]Figures to left of slash for outer wheelpath, to right for inner.

TABLE 3

FLEXIBLE PAVEMENT DEFLECTION SUMMARIES[a]

| When Project Tested | Code | Proj. No. | District | Date Tested | Temp. Range (°F) | Rebound Deflection (thousandths in.) OWP/IWP[b] | | % Defl. Remaining at Indicated Distance Average[b] | | | Structural Thickness (in.) | | Construction Costs ($/lin ft) | | Year Opened to Traffic | TT & B | Soil Area | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Proj. Avg. | Range | 2 Ft | 6 Ft | 9 Ft | A. C. | Total | Actual | Adjusted | | | | |
| In 1962 | III-1 | 0015-019 -101, C-2 (Heavy) | 3 | April | 40-43 | 16/13 | 12-19/11-14 | 50/38 | 6/0 | 0/0 | 7.0 | 19.0 | 13.73 | 12.92 | 1960 | 1,211 | 9 | Deflections measured in 1961 averaged 16/18. No defects noted. |
| | III-2 | 0017-030 -003, C-501 | 7 | May | 72-74 | 26/24 | 18-34/15-32 | 54/42 | 8/4 | 4/0 | 7.0 | 21.0 | 16.21 | 15.89 | 1962 | 271 | 11 | No defects. |
| | III-3 | 0017-030 -003, C-502 | 7 | May | 65-68 | 20/18 | 15-25/15-21 | 50/44 | 10/6 | 0/0 | 7.0 | 21.0 | 18.91 | 15.89 | Incomp. | 271 | 11 | No defects; portion of project not open to traffic. |
| | III-4 | 0017-030 -008 | 7 | May | 80-82 | 18/15 | 7-30/8-24 | 50/47 | 11/13 | 6/4 | 7.0 | 21.0 | 15.56 | 16.02 | 1959 | 271 | 11, 6 | Deflections measured in 1961 averaged 16/14. No defects noted. |
| | III-5 | 0066-029 -101; -076-101 | 7 | May | 85-88 | 22/19 | 16-30/12-25 | 27/26 | 5/5 | 0/0 | 9.5 | 21.5 | 16.77 | 21.35 | 1962 | 367 | 11 | No defects. |
| | III-6 | 0050-034 -101, C-501 | 8 | June | 65-70 | 18/21 | 15-21/17-24 | 27/25 | 3/3 | 0/0 | 7.0 | 17.0 -23.0 | 10.69 -12.21 | 11.82 -14.09 | 1962 | 229 | 7, 4 | Deflections reduced only slightly by addition of lime treatment to subgrade on parts of project. |
| Before 1962 | III-7 | 0220-044 -030 | 2 | April 1960 | | 35/32 | 20-51/22-44 | 58/— | 28/— | 12/— | 7.0 | 23.0 | 14.40 | 13.75 | 1959 | 797 | 8 | No defects noted. |
| | III-8 | 0123-029 -012 | 7 | March 1961 | 52-55 | 33/23 | 23-42/17-30 | 56/56 | 14/18 | 4/9 | 7.0 | 21.0 | 14.75 | 14.40 | 1960 | 123 | 6 | No defects noted. |
| | III-9 | 0236-029 -007 | 7 | March 1961 | 58-61 | 15/14 | 10-18/10-16 | 55/54 | 13/15 | 3/3 | 7.0 | 21.0 | 13.90 | 15.30 | 1960 | 647 | 6 | No defects noted. |

[a]Black base with stabilization in subgrade.
[b]Figures to left of slash for outer wheelpath, to right for inner.

TABLE 4

FLEXIBLE PAVEMENT DEFLECTION SUMMARIES[a]

| Code | Project No. | District | Date Tested | Temp. Range (°F) | Rebound Deflection (thousandths in.) OWP/IWP[b] | | % Defl. Remaining at Indicated Distance Average[b] | | | Structural Thickness (in.) | | Construction Costs ($/lin ft) | | Year Opened to Traffic | TT & B | Soil Area | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Proj. Avg. | Range | 2 Ft | 6 Ft | 9 Ft | A. C. | Total | Actual | Adjusted | | | | |
| IV-1 | 0460-035 -101, C-1, C-2 | 2 | May 62 | 60-63 | 14/17 | 10-20/14-22 | 29/24 | 7/0 | 0/0 | 4.0[c] | 20.0[d] | 8.99 | 9.94 | 1961 | 29 | 7 | No defects noted. |
| IV-2 | 0117-080 -002, C-1 | 2 | May 62 | 70-73 | 19/18 | 13-34/14-27 | 42/39 | 5/5 | 0/0 | 5.5 | 15.5[e] | 12.53 | 13.09 | 1961 | 161 | 7 | No defects noted. |
| IV-3 | 0017-080 -002, C-502 | 2 | May 62 | 74-77 | 19/17 | 13-28/10-28 | 46/47 | 5/8 | 0/2 | 5.5 | 15.5[f] | 13.67 | 13.09 | Incomp. | 178 | 7 | No defects. No appreciable difference between deflections on regular and special design sections. |
| IV-4 | 0015-019 -101, C-2 (Light) | 3 | April 62 | 40-43 | 20/14 | 13-28/6-19 | 50/43 | 10/7 | 0/0 | 4.5 | 16.5 | 11.22 | 10.80 | 1960 | 55 | 9 | No defects noted. |
| IV-5 | 0015-058 -101, C-501 | 4 | April 62 | 52-58 | 20/13 | 15-24/9-15 | 30/31 | 5/8 | 0/0 | 4.5 | 16.5 | 14.05 | 13.40 | 1962 | 55 | 9 | No defects noted. |
| IV-6 | 0058-071 -020 | 3 | April 62 | 72-75 | 23/22 | 19-32/16-32 | 35/45 | 9/14 | 4/5 | 4.0 | 19.0 | 9.42 | 10.25 | 1961 | 245 | 6, 11 | No defects noted |
| IV-7 | 0060-746 HS-1, IS-1 | 3 | April 62 | 51-55 | 18/17 | 10-42/6-31 | 67/65 | 17/24 | 6/6 | 2.5 | 14.5[g] | 6.42 | 7.63 | 1948 | 182 | 6 | Only noticeable defect has been general transverse shrinkage cracking, becoming pronounced after some years. Pavement sealed in 1949, given 1½" resurfacing in 1959. |

[a] Other than black base; cement or lime stabilization in subgrade or subbase.
[b] Figures to left of slash for outer wheelpath, to right for inner.
[c] Penetration macadam.
[d] Includes 6-in. stabilization of subgrade with lime.
[e] Includes 5-in. CTB.
[f] Includes 5-in. CTB, except on special 2,000-ft section where 10-in. lean concrete base was substituted.
[g] Two 6-in. layers of soil-cement.

TABLE 5

FLEXIBLE PAVEMENT DEFLECTION SUMMARIES[a]

| Code | Proj. No. | District | Date Tested | Temp. Range (°F) | Rebound Deflection (thousandths in.) OWP/IWP[b] | | % Defl. Remaining at Indicated Distance Average[a] | | | Structural Thickness (in.) | | Construction Costs ($/lin ft) | | Year Opened to Traffic | TT & B | Soil Area | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Proj. Avg. | Range | 2 Ft | 6 Ft | 9 Ft | A.C. | Total | Actual | Adjusted | | | | |
| V-1A | 0058-041 -012-033 Design A | 3 | March 62 | 59-82 | 81/72 TL | 55-155/47-94 | 30/26 | 1/3 | 0/0 | 9.0 | 25.0 | 12.87 | 14.89 | 1959 | 986 | 6 | From previous deflection measurements in 1959, 1960, and 1961 it was noted that deflections in the traffic lane in Design A have been consistently higher than in other designs, except in the first series of measurements made soon after the project was opened to traffic in 1959. (See Progress Reports 1 and 2, "Experimental Flexible Pavements.") Alligator cracking and rutting now evident in traffic lane in all designs, but most notably in Design A. |
| | | | | | 44/48 PL | 37-48/34-60 | 36/48 | 2/2 | 0/0 | | | | | | | | |
| V-1B | Design B | 3 | March 62 | 59-82 | 42/39 TL | 39-48/28-49 | 26/26 | 0/0 | 0/0 | 7.0 | 25.0 | 11.89 | 13.67 | | | | |
| | | | | | 34/36 PL | 26-42/22-50 | 29/39 | 0/0 | 0/0 | | | | | | | | |
| V-1C | Design C | 3 | March 62 | 59-82 | 53/57 TL | 39-73/40-68 | 23/25 | 2/0 | 0/0 | 5.0 | 25.0 | 10.90 | 12.46 | | | | |
| | | | | | 50/52 PL | 44-60/45-56 | 26/29 | 2/4 | 0/0 | | | | | | | | |
| V-1D | Design D | 3 | March 62 | 59-82 | 52/47 TL | 36-82/26-76 | 23/19 | 0/0 | 0/0 | 4.0 | 25.0 | 10.50 | 11.82 | | | | |
| | | | | | 44/44 PL | 31-61/31-52 | 23/32 | 2/2 | 0/0 | | | | | | | | |
| V-2A | 0360-019 -002; -073-008 Design A | 3 | April 62 | 40-60 | 39/31 TL | 31-50/24-42 | 33/29 | 3/6 | 0/0 | 7.0 | 23.0 | 12.47 | 13.66 | Incomp. | 1,136 | 9 | New project, partly open to traffic, lacked final surface course when tested. Following items common to all 4 designs: 6" treatment of the native soil subgrade with 10% cement; 6" layer of local select borrow from same pit used in earlier projects Code I-6 and I-7. Deflections in Designs A and D of this project are highest of any measured where cement-treated subgrade used. |
| | | | | | 39/42 PL | 32-48/34-46 | 23/26 | 5/2 | 0/0 | | | | | | | | |
| V-2B | Design B | 3 | April 62 | 40-60 | 19/11 TL | 16-22/8-12 | 63/64 | 11/9 | 0/0 | 4.5 | 23.0[c] | 13.11 | 13.77 | | | | |
| | | | | | 22/16 PL | 18-28/14-20 | 50/63 | 5/6 | 0/0 | | | | | | | | |
| V-2C | Design C | 3 | April 62 | 40-60 | 29/14 TL | 18-38/12-17 | 45/50 | 7/14 | 0/0 | 3.0 | 23.0[d] | 12.28 | 12.38 | | | | |
| | | | | | 26/16 PL | 18-37/12-20 | 38/56 | 4/6 | 0/0 | | | | | | | | |
| V-2D | Design D | 3 | April 62 | 40-60 | 60/42 TL | 36-82/25-59 | 18/17 | 2/2 | 0/0 | 4.5 | 23.0 | 11.60 | 12.25 | | | | |
| | | | | | 46/48 PL | 28-50/26-62 | 20/21 | 4/4 | 0/0 | | | | | | | | |

[a]Special experimental projects.
[b]Figures to left of slash for outer wheelpath, to right for inner.
[c]Includes 6-in. CTB.
[d]Includes 4-in. CTB.

are made between asphaltic concrete and crushed aggregates, both treated and untreated, as base types on a cement-treated subgrade.

This second project was not complete when the deflections were measured, which may at least partially account for the relatively high deflections recorded for Designs A and D. A subsequent series of tests made in December 1962, produced substantially lower values, particularly in the outer wheelpaths, but part of the reduction may have been due to the different season of the year. Still further tests are planned for spring 1963.

## SUMMARY OF RESULTS

The data tabulated here tend to confirm what has seemed evident throughout the seven years of deflection testing in Virginia: that pavements built in certain soil areas are much more likely to exhibit high deflections than pavements built in other soil areas. The poorest soils areas from a deflection standpoint are in the Piedmont section, in the Culpeper, Lynchburg, and Richmond Districts.

Piedmont Virgina soils tend to be quite heterogeneous, ranging in BPR classification from A-2-4 (0) to A-7-6 (20). The types most frequently found are A-4, A-5, and A-7-5, and the one characteristic most commonly associated with these soils is the presence of substantial percentages of mica.

In this report, 13 projects are listed that are not located in the Piedmont; none of these produced deflections higher than 0.025 in., regardless of pavement type or thickness. Of these 13 projects, 3 (Codes I-9, I-10, and I-18) are in the Coastal Plains and 10 (Codes I-1, I-16, I-17, I-19, I-20, II-1, III-6, IV-1, IV-2, and IV-3) are in the Valley and Ridge Province. Soils in the Coastal Plains (Area 1) usually contain high percentages of sand, whereas the Valley soils (Areas 4 and 7) most commonly are heavy clays or shales. In these areas, the magnitude of deflection apparently has little to do with the problems of pavement behavior.

It is in consideration of the data from the forty projects in the Piedmont that the maximum value can be obtained from these deflection studies. Accordingly, Table 6 summarizes the data from these projects only. In this table, the data from the experimental sections of the projects on Routes 58 and 360 from Table 5 have been worked into the summary in the proper pavement category described previously in connection with Tables 1, 2, 3, and 4.

It is recognized that the significance of some of the differences between corresponding figures in Table 6 may be debatable. Simple averages and ranges of values are often influenced to a major extent by extreme values for individual projects. Though all measurements were made as soon as possible after the frost was known to be out of the ground, obviously there were differences in temperature and natural ground moisture between projects tested early in the program and those tested later. These differences could have had an appreciable effect on readings. No positive conclusions can be advanced, therefore, regarding the relative merits of black base pavements and non-black base pavements under similar subgrade conditions.

There does seem, however, to be a marked difference between the figures for pavements that include no stabilization (Types I and II) and those that do include cement

TABLE 6

SUMMARY FOR PAVEMENTS IN PIEDMONT SECTION ONLY

| Type Code | No. of Projects | Black Base | Lime or Cement Stabilization | Rebound Deflection[a] (thousandths in.) | | % Deflection Remaining at Indicated Distances[a] (grand avg.) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Grand Avg | Range | 2 Ft | 6 Ft | 9 Ft |
| I | 14 | Yes | No | 46.2/41.6 | 13-173/12-148 | 31.9/34.6 | 3.9/4.6 | 0.5/0.7 |
| II | 10 | No | No | 46.1/42.3 | 16-111/14-92 | 28.6/27.8 | 3.6/3.2 | 1.0/0.8 |
| III | 9 | Yes | Yes | 24.2/21.0 | 7- 51/8 -44 | 44.6/41.9 | 8.1/9.8 | 2.0/2.4 |
| IV | 7 | No | Yes | 27.0/19.0 | 10- 82/6 -59 | 44.0/45.0 | 8.7/11.1 | 1.4/1.5 |

[a]Figures to left of slash for outer wheelpath, to right for inner.

stabilization in either the subgrade or the base or both (Types III and IV). (In considering only the projects in the Piedmont, no lime stabilization is included. The only two projects with lime stabilization (III-6 and IV-1) are located in the Valley and Ridge Province.) These differences are consistent across the board, so to speak, in that the averages, the minimum single group values, and the maximum single group values for Types III and IV are seldom much more than one-half the corresponding values for Types I and II. Furthermore, the distribution of the loads to the subgrade seems to be noticeably better, generally, on projects of Types III and IV; this observation is based on the higher average values of percentage of deflection remaining after the test load has moved certain specified distances away from the point of measurement.

The use of cement-treated subgrades thus seems to be providing a most effective solution to the problem of fatigue failures caused by high deflections in the Piedmont soil areas.

## Deflection vs Performance

In further summary, the 53 separate pavements in this report have been classified with respect to (a) traffic volume and (b) average rebound deflection value in an attempt to learn what maximum deflection can be withstood under various conditions. Traffic volumes are classified as light (less than 200 TT & B daily), medium (200-699 TT & B daily), and heavy (700 or more TT & B daily). The following remarks summarize the findings:

1. Pavements exhibiting very low average deflections (less than 0.020 in.). Many of the 18 pavements in this group are new or nearly so. Among the older ones, only two have required appreciable upkeep expenditure. Both of these relatively inexpensive pavements (I-10 with local sand asphalt base and IV-7 with a soil cement base) have required resurfacing on account of transverse cracks which seem unrelated to deflection. Five pavements (I-1, I-16, I-18, I-19, and III-1) have carried heavy traffic without distress for some time now, one for a period of 11 years.
2. Pavements exhibiting low average deflections (0.020 to 0.030 in.). Four of these 10 pavements are less than two years old. One of the older ones (II-1) developed numerous areas of distress in the original mixed-in-place surface, but has performed well since being resurfaced. None of the others have required appreciable maintenance, although three carry traffic classified as heavy.
3. Pavements exhibiting medium average deflections (0.030 to 0.040 in). Most of the 10 pavements in this group are from 2 to 6 years old. Three carry heavy traffic: one of these has developed occasional pronounced alligator cracking (V-1B); another (III-7) shows no defects yet, but the deflections are well distributed; the third is new (V-2A). Four carry medium traffic: the two older ones (I-2 and I-15) have both required resurfacing due to development of pronounced cracking and rutting; the two newer ones show no defects after four winters. Three carry light traffic: the oldest of these (II-5) has been resurfaced once and is in distress again for reasons that are not clear in view of the light traffic; no defects have appeared on the other two.
4. Pavements exhibiting high average deflections (0.040 in. and higher). Fifteen pavements make up this group which would naturally be expected to display considerable distress. As expected, nearly all have developed pronounced distress, including two that carry only light traffic (I-13 and II-4). On seven, the distress has been severe enough to warrant at least partial resurfacing with asphaltic concrete. On two (I-12 and II-7), the distress seems to be developing surely but perhaps more slowly than might be expected. One pavement was not yet open to traffic when tested (V-2D).

In view of the foregoing, it is felt that the observations made previously (1, p. 21) are still justified. Briefly, it was stated that flexible pavements whose average deflections under an 18,000-lb axle load exceed 0.036 in. and which are subjected to heavy or medium heavy traffic may be expected to develop early distress in the form of alligator cracking and rutting.

<u>General Observations</u>

Data from a number of specific projects, if singled out and subjected to scrutiny, may be found of considerable interest. On such a basis, the following observations are offered:

1. The use of soil cement or cement-treated aggregates for base courses seems to be quite effective in lowering deflections. (IV-2, IV-3, IV-7, V-2B, and V-2C). There are drawbacks, however:

(a) These more rigid bases may not be able to stand as high deflections as can more flexible bases, especially if such deflections occur with considerable frequency.

(b) The presence of higher percentages of cement immediately beneath the surface often leads to shrinkage cracks which are reflected through the surface and produce something of a maintenance problem. Close observation of the performance of the cement-treated aggregate bases on Route 117 (IV-2 and -3) and Route 360 (V-2 designs B and C) may show how much of a cracking problem can develop from this type of construction.

2. Relatively high deflections, in comparison with other projects whose designs include subgrade stabilization, are recorded for projects III-7 and III-8 (Route 220, Henry County; and Route 123, Fairfax) and for experimental designs V-2A and V-2D (Route 360, Charlotte and Prince Edward). A noticeable difference exists, however, in that deflections on III-7 and III-8 are better distributed, indicating that the entire structure is behaving like a slab and deflecting on a resilient layer beneath the stabilized subgrade. On pavements V-2A and V-2D, the distribution is poorer, indicating perhaps that much of the deflection originates within the structure itself, probably above the stabilized subgrade layer.

3. Referring further to the experimental project on Route 360 (V-2), every design includes a layer of crushed stone (either treated or untreated) and a layer of local select material. In designs B and C the crushed stone is treated with cement which has tended to minimize the deflections. It has been suspected that resilience in the local material may have caused the high deflections measured in designs A and D. However, a nearby pavement (I-6), which includes local material from the same pit but no crushed stone, has performed well and shows moderately low deflections. At the same time, still another nearby pavement (I-7), built more recently and including both the crushed stone (untreated) and the same local material, exhibits very high deflections and has performed very poorly. There is reason therefore to suspect that the crushed stone rather than the local material may be to blame.

There is an urgent need in Virginia for a laboratory method of measuring the potential resilience of materials proposed for use in pavements or their subgrades, so that the disastrous effects of high deflections on expensive pavements may be avoided. The CBR test falls far short of answering this need.

4. The addition of overlays of the usual thickness of $1\frac{1}{2}$ in. has had an uncertain effect on deflections. One pavement (I-14) is observed to be deflecting more since being overlaid than before; another, partly resurfaced when tested (I-15), deflected no less where resurfaced than where the original cracked surface remained. Still other projects seem to have been greatly improved by overlays (I-2, I-5, and II-3).

## PAVEMENT COST ANALYSIS

It has been noted that two columns in the tabulations are included to indicate "actual" and "adjusted" construction costs per linear foot per roadway. These costs include all operations performed after completion of what is classed as "regular excavation," and includes materials imported to build shoulders. "Actual" costs were computed from actual contract unit prices; "adjusted" costs were determined by substituting the same typical assumed unit costs into the computation for each pavement. The unit costs used for this purpose were the following:

1. $7.00 per ton for asphaltic concrete binder or surface course materials.
2. $6.00 per tone for H-3 (1) asphaltic concrete base course material. Where actual bid prices were on a square yard basis, a figure of 130 lb per sq yd per in. of depth was used for the necessary conversion.
3. $5.50 per ton for hot-mixed black base materials with aggregates obtained from local pits.
4. $5.50 per cu yd for aggregate base materials of all types produced by commercial quarries. (Cubic yard units usually measured as finally compacted in place; no allowance made for thickness in excess of that shown on plans.)
5. $4.70 per cu yd for aggregate subbase materials of all types produced by commercial quarries.
6. $3.00 per cu yd for select material Type I, CBR 20 or higher, produced by commercial quarries or traveling crushers.
7. $2.75 per cu yd for aggregate base or subbase materials available from local pits.
8. $2.00 per cu yd for select material or select borrow, CBR 20 or higher, available from local pits.
9. $1.50 per cu yd for any borrow blanket material available on the job or within very close haul.
10. $5.00 per bbl for cement used in stabilization.
11. $25.00 per ton for hydrated lime used in stabilization.
12. $0.35 per sq yd for manipulation involved in road-mix stabilization operations.

These unit costs were selected after study of statewide averages from all construction bids, prepared by the Traffic and Planning Division, and study of typical Interstate job prices. They may be low, if applied to secondary or small primary projects, or somewhat high if applied to very large Interstate projects. The one estimated price most often higher than the corresponding actual bid price is for the item of borrow available within close haul; the $1.50 price makes the adjusted cost of pavements on some projects or parts of projects seem unreasonably high. All in all, however, the adjusted cost approach makes cost comparisons between different pavements much more reasonable.

These cost computations were included to permit careful study of the relative cost of various pavements built for similar conditions of traffic, soil, and climate. They will admit some insight into the benefits in relation to the costs involved, of such costly features of many recent pavement designs as the following, for example:

1. "Black base" construction.
2. Full roadway width construction of commercial aggregate base, subbase, and select borrow materials.
3. Stabilization of subgrades and bases with cement and lime.

Black bases cost from two to more than four times as much per inch of thickness as untreated aggregate bases. But at the AASHO Road Test it was found that the asphaltic concrete used in that installation had over three times the load supporting power of the crushed stone base material and four times that of the gravel subbase material (3, p. 89). If this relationship were universally true, then the greatest economy should result from designs that would include nothing but asphaltic concrete.

The superiority of black bases over aggregate bases was rather generally proclaimed at the International Conference on the Structural Design of Asphalt Pavements at Ann Arbor, Mich., in August 1962 (4, 5). The ratios of superiority or equivalent factors, varied markedly, and even when computed from the same data from the AASHO Road Test, the factors ranged from 2.6 to 6.7, depending on the method of analysis used.

In view of the preceding, it is surprising to note in the "remarks" column of Table 1 that seven black base projects built between 1954 and 1959 have developed serious distress necessitating at least partial resurfacing (I-2, I-5, I-7, I-11, I-13, I-14, and I-15). In addition, pavement V-1A of the experimental project on US 58, the design which included 9 in. total asphaltic concrete thickness, has not performed as well as pavement V-1D, which included only 4 in. in the same total structural thickness. Although the advantages of a moderately thick bituminous mat in providing cohesion and resistance to surface shear stresses are well recognized, it is felt that Virginia's experiences tend to minimize these advantages and should be reported.

The second costly feature of many recent pavement designs, ditch-to-ditch construction with densely-graded aggregate subbase materials, is more difficult to evaluate. Barber (6) has pointed out that the densely-graded bases often have permeabilities less than that of the surface. Particularly, when a subbase is densely graded and is also covered by a penetrating prime treatment, it tends to pond water in the more open-graded black base above. The whole subject of structural section drainage is a complex one and is not within the scope of this report.

There is evidence, however, that a properly stabilized subgrade that cannot be softened by free water from above combined with a system of properly compacted granular materials of good quality can produce good performance without extensive efforts at subdrainage. An example of this is furnished by project I-18, built over 10 years ago by the then-standard trench design. On the day the deflection measurements were made on this project, the shoulder material was so saturated it would not support a passenger automobile. Other examples are afforded by projects I-3 and III-1; on both of these projects excavation at the edge of the pavement on the day after a heavy rain resulted in a lively flow of free water from the saturated "black base," and yet performance has been good on these projects through four and two winters, respectively.

The effect of the adoption of both black base and full width subbase construction as the standard for Interstate designs has been quite marked. Costs of this type of construction, using the "adjusted" unit price scale, have exceeded $21.00 per linear foot, and in view of the most recent bid prices on Select Material Type I, estimated costs probably should be higher yet. Performance of the few projects of this type now open to traffic (I-1, I-16, I-17, I-19, I-20) has been good, but none of these projects is located in the Piedmont; therefore, none is subjected to high deflections.

There is evidence that performance comparable to that afforded by present Interstate designs can be obtained at substantially less cost. The pavement design of project III-1, for example, has a subbase only 26 ft wide, has 2½ in. less asphaltic concrete than the Interstate designs, but does include a cement-treated subgrade. The total actual cost of construction was only $13.73 per linear foot. Substitution of a surface-treated soil cement shoulder pavement for the untreated crushed aggregate shoulder surfacing should not add more than $1.25 per linear foot, resulting in a total cost still less than $15.00. Facts that should not be overlooked in considering the wisdom of using such designs are (a) that the saving involved would more than defray the cost of the first three 150-lb per sq yd resurfacings, and (b) that at least one such resurfacing can be programed initially to be financed as a final stage in two stage construction.

Deflection and performance studies to date have indicated that the use of subgrade stabilization has been well worth the modest cost involved. The benefits received from the other two features are still open to question.

## CONCLUSIONS AND RECOMMENDATIONS

An obvious conclusion from study of the tabulated deflection data and the foregoing summaries is that fatigue failures resulting from repeated high deflections are a major cause of flexible pavement distress in Virginia, especially in the Piedmont section.

A further conclusion might be copied from a paper prepared earlier by the author for presentation at the International Conference on Structural Design of Asphalt Pavements. This paper, prepared to meet a publication deadline of February 1, 1962, included none of this year's deflection data. Nevertheless, the following conclusion was expressed.

> Flexible pavement performance is affected to a greater extent by the degree of support offered by the underlying layers than by the thickness of asphaltic concrete in the upper portion of the structure; strength and resistance to deflection can be improved appreciably through better

> control over base and subbase compaction, but more significantly through stabilization of the subgrade with lime or cement.

This conclusion seems even further justified now.

A third conclusion, relating to the technique of deflection measurement with the Benkelman beam, is that the procedure described herein produces accurate data in adequate detail at a maximum rate of accomplishment. The fact that on most pavements an appreciable percentage of the deflection still remains when the test load has advanced a distance of 6 ft indicates clearly that the old WASHO method of attempting to measure deflection was often in error because both the point of measurement and the forward supports were within the area influenced by the load when the initial reading was taken (each being only 4½ ft away). The process of measuring deflection by backing the truck over the point of measurement and pulling forward again is tedious and time consuming, and graphical recording of the data by means of the Helmer apparatus is considered to produce greater than necessary detail.

The final, but by no means the least significant, conclusion is that many relatively low cost pavements resist deflection as well, or practically as well, as many others that carry a very high price tag.

In view of the foregoing, the following recommendations are made:

1. Laboratory tests used in the design of flexible pavements should include some measure of the potential resilience of roadbed soils. (Various test methods are being considered, and pilot studies to evaluate at least two such methods on Virginia soils are scheduled to get under way soon.)
2. Efforts should be made to develop workable procedures for "proof testing" subgrades and bases to discover and correct areas of high deflection during construction before application of the more expensive black base and surfacing elements. It is believed that the Benkelman beam can be used effectively for this purpose and that the tests can be made rapidly enough to avoid unnecessary delays in construction schedules.
3. Stage construction should be programed more often for flexible pavements, with a considerable portion of the more expensive asphaltic concrete applied from one to several years after the initial stage has been opened to traffic.

The stage construction concept advanced in the last recommendation points out one of the principal advantages offered by flexible pavement designs over rigid designs. It is the author's considered opinion that it is a mistake to attempt to construct in a single paving contract any type of pavement that would be expected to last indefinitely, or even for as long as ten years, without some likelihood of its needing a renewal of the surface course. A far more economical approach involving a minimum of risk is one in which a design such as III-1, mentioned earlier, or even IV-6, still less expensive, would be programed as the initial stage of what would ultimately become a two-stage construction project. A few years later, then, after any weak spots have shown up and been corrected, after the apparently inevitable settlements around drainage structures have occurred, and after the entire road structure has become comfortable in its environment, a new asphaltic concrete riding surface would be placed to iron out all irregularities. The total cost of such two-stage construction, even including cement stabilization and surface treatment on the shoulders if desired, would still be substantially below that of most rigid pavement designs and many flexible designs commonly used for single-stage construction in Virginia.

## ACKNOWLEDGMENTS

Each spring for the past several years selected flexible pavements in various parts of the State have been tested for deflection, and it is felt that a continuation of such a program will result in a more thorough understanding of pavement behavior. But such a test program would be impossible without the splendid cooperation received from the field forces in the immediate area, who furnish the test truck and, usually, all except one man of the test crew. The individuals in the 16 residencies involved in the last two years who have helped with this work are too numerous to be listed in full, but the efforts of each, from Resident Engineer down, are sincerely appreciated.

The one representative of the Research Council present for each series of deflection tests was R. W. Gunn, of the Pavement Evaluation Section. His efforts in organizing and instructing green crews in the test procedure, in pushing the testing to completion, and in summarizing the results for publication, have given the Department of Highways the benefit of a maximum amount of information at a bare minimum of cost. His interest and enthusiasm in his work deserve special mention here.

This report is the first issued since initiation of the Pavement Design and Performance Study being conducted in cooperation with the Bureau of Public Roads. The financial assistance from HPS funds and the interest and encouragement of Stuart Williams, Supervisory Highway Research Engineer, are gratefully acknowledged.

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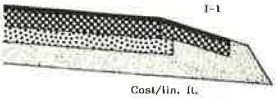
3. "The AASHO Road Test, Report 5." HRB Special Report 61E (1962).
4. Dorman, G. M., "The Extension to Practice of a Fundamental Procedure for the Design of Flexible Pavements." Proc., Internat. Conf. on the Structural Design of Asphalt Pavements, Univ. of Mich. (1962).
5. Shook, J. F., and Finn, F. N., "Thickness Design Relationships for Asphalt Pavements." Proc., Internat. Conf. on the Structural Design of Asphalt Pavements, Univ. of Mich. (1962).
6. Barber, E. S., "The Properties of Granular Materials." Proc., 10th Highway Materials Conf., Virginia Council of Highway Investigation and Research, p. 7 (Sept. 1962).

# *Appendix A*

## PRINCIPAL PAVEMENT SECTIONS—PROJECTS IN TABLE 1

Surface $\frac{1}{2}$" F-1 (Mod)
Binder 1" H-2
Base $7\frac{1}{2}$" H-3 (1)
Subbase 6" Cr. Aggr.
Subbase 9" Select B.

I-1



Cost/lin. ft.
Actual $16.09
Adjusted 18.31

Surface 1" I-3
Binder $1\frac{1}{2}$" H-2
Base $5\frac{1}{2}$" H-3 (1)
Subbase 4" Cr. Aggr.
Resurface $1\frac{1}{2}$" I-3

I-2

Cost/lin. ft.
Actual $10.38
Adjusted 9.47

Surface $1\frac{1}{2}$ I-3
Base $5\frac{1}{2}$" H-3 (1)
Subbase 8" Cr. Aggr.

I-3

Cost/lin. ft.
Actual
Adjusted $10.45

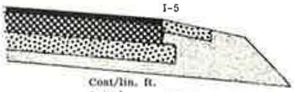
Surface: $1\frac{1}{2}$" I-3
Base : $5\frac{1}{2}$" H-3 (1)
Subbase: 8" Cr. Aggr.

I-4

Cost/lin. ft.
Actual
Adjusted $10.45

Surface : $1\frac{1}{2}$" I-3
Base : $5\frac{1}{2}$" H-3
Subbase : 5" Cr. Aggr.
Subbase : 0"-24" Select B.
CBR 12
Resurface: $1\frac{1}{2}$" I-3 8-6-59

I-5



Cost/lin. ft.
Actual $10.51 - 12.10
Adjusted 10.04 - 16.01

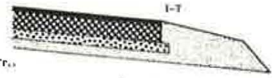
Surface: $1\frac{1}{2}$" F-1
Base : $7\frac{1}{2}$" H-3 (1)
Subbase: 6" Subgr. Tr.
(Local Aggr.)

I-6

Cost/lin. ft.
Actual $9.55
Adjusted 11.89

Surface: $1\frac{1}{2}$" F-1 Mod.
Base : $7\frac{1}{2}$" H-3 (1)
Subbase: 4" Cr. Aggr.
Subbase: 4" & Var. Subgrade. Tr.
(Local Aggr.)

I-7



Cost/lin. ft.
Actual $14.35
Adjusted 13.83

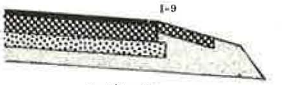
Surface: 1" F-1
Base : 7" H-3 (1)
Subbase: 6" & Var. Select B.
CBR 28

I-8

Cost/lin. ft.
Actual $6.60
Adjusted 10.48

Surface: 2" F-1 Mod.
Base : $7\frac{1}{2}$" H-3 (1)
Subbase: 6" Cr. Aggr.
Subbase: 6" Select B.
CBR 30

I-9



Cost/lin. ft.
Actual $15.03
Adjusted 19.09

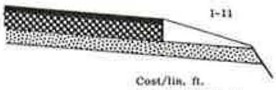
Surface : $1\frac{1}{2}$" F-1
Base : $5\frac{1}{2}$" F-1 (mod.)
Subbase : 6" Subgr. Tr.(Local)
Resurface: $1\frac{1}{2}$" F-1 1955 & 1956
Resurface: $1\frac{1}{2}$" F-1 1960

I-10

Cost/lin. ft.
Actual $5.23
Adjusted 9.38

Surface: $1\frac{1}{2}$ F-1
Base : $7\frac{1}{2}$ H-3 (1)
Subbase: 6" Subgr. Tr.
(Local Aggr.)

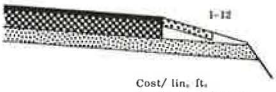
I-11



Cost/lin. ft.
Actual $8.44
Adjusted 10.91

Surface $1\frac{1}{2}$" F-1
Base $7\frac{1}{2}$" H-3 (1)
Subbase 6" Subgrade Tr.
(Local Aggr.)

I-12



Cost/ lin. ft.
Actual $10.39
Adjusted 11.38

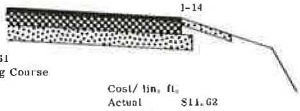
Surface $1\frac{1}{2}$" I-3
Base $5\frac{1}{2}$" H-3 (1)
Subbase 3" Subgr. Tr.
Subbase 6" & 12" Select B.
Resurface $1\frac{1}{2}$" I-3 October 1961

I-13

Cost/ lin. ft.
Actual $11.86
Adjusted 12.82

Surface $1\frac{1}{2}$" I-3
Base $5\frac{1}{2}$" H-3 (1)
Subbase 6" Cr. Aggr.
Resurface $1\frac{1}{2}$" I-3 June 1961
H-2 Leveling Course

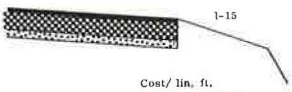
I-14



Cost/ lin. ft.
Actual $11.62
Adjusted 10.21

Surface $1\frac{1}{2}$" I-3
Base $7\frac{1}{2}$" H-3 (1)
Subbase 3" Cr. Aggr.

I-15



Cost/ lin. ft.
Actual $9.54
Adjusted 10.62

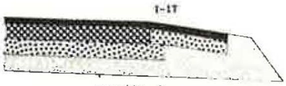
Surface 1/2" F-1
Binder 1 1/2" H-2
Base 7 1/2" H-3 (1)
Sub-base 6" Soil Aggr.
Sub-base 9" CBR 30

I-16

Cost/ lin. ft.
Actual $16.68
Adjusted 21.53

Surface 1/2" F-1 Mod
Binder 1 1/2" H-2
Base 7 1/2" H-3(1)
Sub-base 6" Soil Aggr.
Sub-base 9" CBR 30

I-17



Cost/ lin. ft.
Actual $19.86
Adjusted 21.53

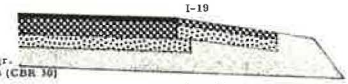
Surface : $2\frac{1}{2}$" F-1
Base : 6" Loc. Agg.
Bit. Conc.
Sub-base: 8" & 10" Local M.

I-18

Cost/ lin. ft.
Actual $5.52
Adjusted 8.00 - 8.29

Surface 1/2" F-1
Binder 1 1/2" H-2
Base 7 1/2" H-3(1)
Sub-base 6" Soil Aggr.
Sub-base 12 Select B (CBR 30)

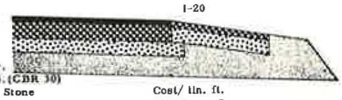
I-19



Cost/ lin. ft.
Actual $16.67
Adjusted 21.11

Surface 1/2" F-1
Binder 1 1/2" H-2
Base 7 1/2" H-3(1)
Sub-base 6" Soil Aggr.
Sub-base 12" Select B.(CBR 30)
Crushed Stone

I-20

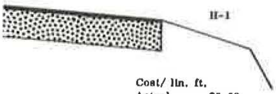


Cost/ lin. ft.
Actual $
Adjusted 21.11

## PRINCIPAL PAVEMENT SECTIONS—PROJECTS IN TABLE 2

Surface 1" M.I.P.
Base 12" Cr. Aggr.
Resurface 1½" I-3 1960

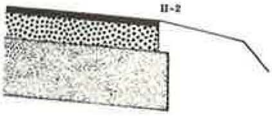
II-1



Cost/ lin. ft.
Actual $5.52
Adjusted 6.21

Surface: 2" H-2
Base: 11" Graded Aggr.
Subbase: 24" Select B.

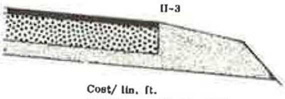
II-2



Cost/ lin. ft.
Actual $8.88
Adjusted 9.84

Surface : 2½" H-2
Base : 12 " Graded Aggr.
Subbase : 6", 10" & 16" Select B.
Resurface: 1½" F-1 July 1957

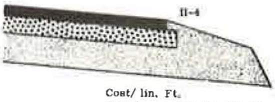
II-3



Cost/ lin. ft.
Actual $9.08 - 9.75
Adjusted 9.72 - 11.96

Surface 1½" I-3
Binder 3" H-3 (1)
Base 7" Cr. Aggr.
Subbase 12" & 18" Select B.

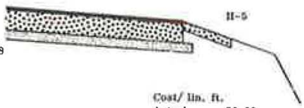
II-4



Cost/ lin. Ft.
Actual $11.58 - 12.55
Adjusted 11.57 - 13.03

Surface 1" M.I.P.
Base 8" Cr. Aggr.
Subbase 4" Subgr. Tr.
Resurface 1½" I-3 1958

II-5



Cost/ lin. ft.
Actual $6.52
Adjusted 5.31

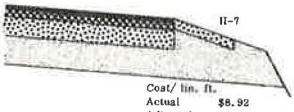
Surface 1" I-3
Binder 3" H-3 (1)
Base 8" Cr. Agge.
Subbase Var. Select B.

II-6

Cost/ lin. ft.
Actual -
Adjusted $10.61

Surface 1½" I-3
Binder 3" H-3 (1)
Base 8" Cr. Aggr.
Subbase 12" Select B.

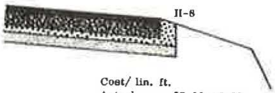
II-7



Cost/ lin. ft.
Actual $8.92
Adjusted 8.73

Surface 2" F-1
Base 8" W. B. Macadam
Subbase 3" Subgr. Tr.
Subbase 0", 4", 13", 16" Select B.
Resurface 1" I-3 1958
Resurface Seal 1961

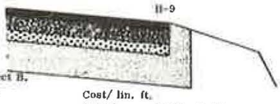
II-8



Cost/ lin. ft.
Actual $7.18 - 8.59
Adjusted 6.85 - 8.29

Surface 1" Surface Tr.
Binder 2" Bit. Pentr.
Base 6" Macadam
Subbase 4" Cr. Aggr.
Subbase 0", 14", 35" Select B.
Resurface 1½" I-3 1958

II-9

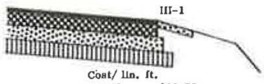


Cost/ lin. ft.
Actual $8.47 - 9.57
Adjusted 8.21 - 10.93

## PRINCIPAL PAVEMENT SECTIONS—PROJECTS IN TABLE 3 AND 4

Surface 1½" I-3
Base 5½" H-3 (1)
Subbase 6 " Cr. Aggr.
Subbase 6 " Cement Tr.

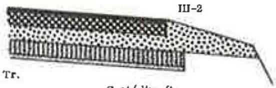
III-1



Cost/ lin. ft.
Actual $13.73
Adjusted 12.92

Surface 1½" I-3
Base 5½" H-3 (1)
Subbase 6" Cr. Aggr.
Subbase 8" Select B with Cement Tr.

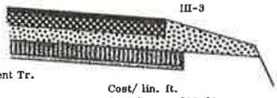
III-2



Cost/ lin. ft.
Actual $16.21
Adjusted 15.89

Surface 1½" F-1
Base 5½" H-3 (1)
Subbase 6" Cr. Aggr.
Subbase 8" Select B with Cement Tr.

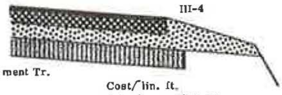
III-3



Cost/ lin. ft.
Actual $18.91
Adjusted [illegible]

Surface 1½" I-3
Base 5½" H-3 (1)
Subbase 6" Cr. Aggr.
Subbase 8" Select B. with Ce ment Tr.

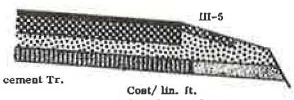
III-4



Cost/ lin. ft.
Actual $15.56
Adjusted 16.02

Surface ½" F-1
Binder 1½" H-2
Base 7½" H-3 (1)
Subbase 6" Cr. Aggr.
Subbase 6" Select B with cement Tr.

III-5



Cost/ lin. ft.
Actual $16.77
Adjusted 21.35

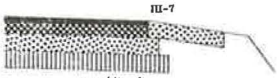
Surface ¾" F-4
Binder 1½" H-2
Base 5½" H-3(1)
Subbase 10" Select B.
Subbase 6" Lime Tr.

III-6

Cost/ lin. ft.
Actual $12.69 - 12.21
Adjusted 11.82 - 14.09

Surface 1 1/2" I-3
Base 5 1/2" H-3 (1)
Sub-base 8" Soil Aggr.
Sub-base 8" Cement Stab.

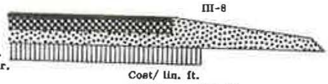
III-7



Cost/ lin. ft.
Actual $14.40
Adjusted 13.75

Surface : 1½" I-3
Base : 5½" H-3 (1)
Prime : MC-0
Sub-base: 6" Cr. Aggr.
Sub-base: 8" Cement Tr.

III-8



Cost/ lin. ft.
Actual $14.75
Adjusted 14.40

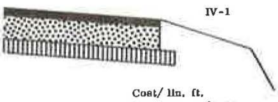
Surface : 1.5" I-3 Bit. Conc.
Base : 5.5" H-3 (1) Bit. Conc.
Prime : MC-0
Sub-base: 6" Subgrade Tr. Matl. C or D
Sub-base: 8" Cement Tr.

III-9

Cost/ lin. ft.
Actual $13.90
Adjusted 15.30

Surface 1" M.I.P.
3" Pentr. Macadam
Base 10" Cr. Aggr.
Subbase 6" Lime Tr.

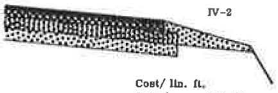
IV-1



Cost/ lin. ft.
Actual $8.99
Adjusted 9.94

## PRINCIPAL PAVEMENT SECTIONS--PROJECTS IN TABLE 3 AND 4 (Continued)

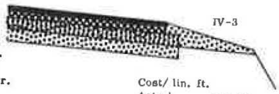
Surface ¼" F-4
Binder 1¼" H-2
Binder 4" H-3 (2)
Base 5" Cement Tr. Cr. Aggr.
Subbase 5" Cr. Aggr.



IV-2

Cost/ lin. ft.
Actual $12.53
Adjusted 13.09

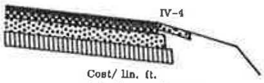
Surface ¼" F-1
Binder 1¼" H-2
Binder 4" H-3 (2)
Base 5" Cement Tr. Cr. Aggr.
Subbase 5" Cr. Aggr.



IV-3

Cost/ lin. ft.
Actual $13.67
Adjusted 13.09

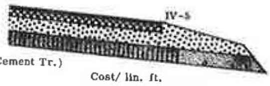
Surface: 1½" I-3
Binder : 3" H-3 (1)
Base : 6" Cr. Aggr.
Subbase: 6" Cement Tr.



IV-4

Cost/ lin. ft.
Actual $11.22
Adjusted 10.80

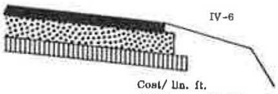
Surface: 1½" I-3
Binder : 3" H-3 (1)
Base : 6" Cr. Aggr.
Subbase: (6 " Select Mat'l Cement Tr.)



IV-5

Cost/ lin. ft.
Actual $14.05
Adjusted 13.40

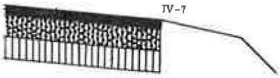
Surface 1½" I-3
Binder 2½" H-2
Base 9" Cr. Aggr.
Subbase 6" Cement Tr.



IV-6

Cost/ lin. ft.
Actual $9.42
Adjusted 10.25

Surface : 1" F-1
Binder : 1½" H-2
Base : 6" Select Material Cement Tr.
Subbase : 6" Cement Tr.
Resurface: 1½" I-3, Oct. 1959

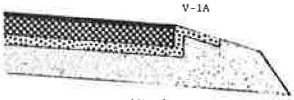


IV-7

Cost/ lin. Ft.
Actual $6.42
Adjusted 7.63

## PRINCIPAL PAVEMENT SECTIONS—PROJECTS IN TABLE 5

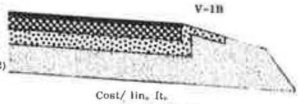
Surface 1½" I-3
Base 7½" H-3 (1)
Subbase 4" Cr. Aggr.
Subbase 12" Select D. (CBR 12)



V-1A

Cost/ lin. ft.
Actual $12.87
Adjusted 14.89

Surface 1½" I-3
Base 5½" H-3 (1)
Subbase 6" Cr. Aggr.
Subbase 12" Select B. (CBR 12)



V-1B

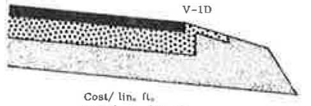
Cost/ lin. ft.
Actual $11.89
Adjusted 13.67

Surface 1½" I-3
Binder 3½" H-3 (1)
Base 8" Cr. Aggr.
Subbase 12" Select B (CBR 12)

V-1C

Cost/ lin. ft.
Actual $10.90
Adjusted 12.46

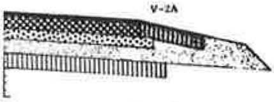
Surface 1½" I-3
Binder 2½" H-2
Base 9" Cr. Aggr.
Subbase 12" Select B (CBR 12)



V-1D

Cost/ lin. ft.
Actual $10.50
Adjusted 11.82

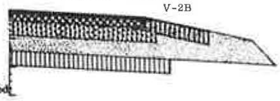
Surface 1.5" I-3
Base 5.5" H-3 (1)
Subbase 4" Cr. Aggr.
Subbase 6" Select M.
Subbase 6" Cement Tr.



V-2A

Cost/ lin. ft.
Actual $12.47
Adjusted 13.66

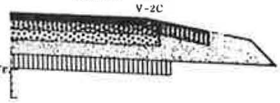
Surface 1.5" I-3
Binder 3" H-3 (1)
Base 6" Cr. Aggr. Cement Treated
Subbase 6.5" Select M.
Subbase 6" Cement Treated



V-2B

Cost/ lin. ft.
Actual $13.11
Adjusted 13.77

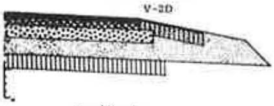
Surface 1.5" I-3
Binder 1.5" H-2
Base 6" Cr. Aggr. with top 4" Cement Tr.
Subbase 6" Select M.
Subbase 6" Cement Tr.



V-2C

Cost / lin. ft.
Actual $12.28
Adjusted 12.38

Surface 1.5" I-3
Binder 3" H-3 (1)
Base 6" Cr. Aggr.
Subbase 6.5" Select M.
Subbase 6" Cement Tr.



V-2D

Cost/ lin. ft.
Actual $11.60
Adjusted 12.25

# *Appendix B*

## GENERAL SOIL AREAS OF VIRGINIA

Figure 3 shows a map of Virginia divided into twelve general soil areas. This map was originally published in a paper by Stevens, Maner, and Shelburne, "Pavement Performance Correlated with Soil Areas" in the Highway Research Board Proceedings of 1949. General soil areas were selected on the basis of geological formations and past experience, and were numbered in the approximate order of suitability of the predominant soil types as highway subgrades, as seemed evident to the authors from their analysis of condition survey data from the spring break-up of 1948.

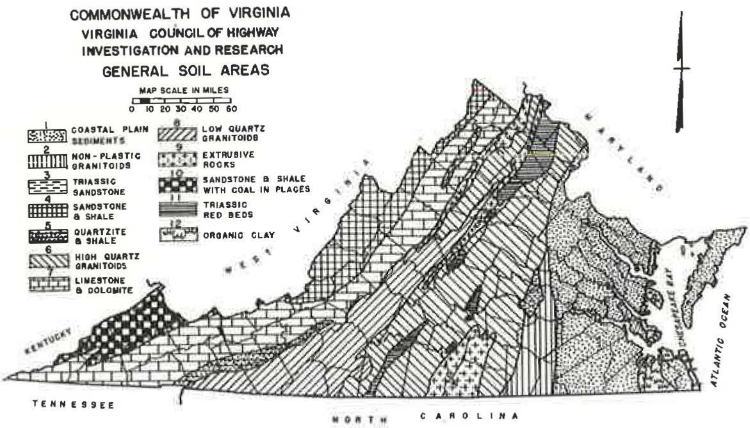



Figure 3. Map of Virginia showing general soil areas.

# *Appendix C*

## SPECIFICATIONS AND PROPERTIES OF TYPICAL VIRGINIA PAVING MATERIALS

### Asphaltic Concretes

| Type | Gradation Tolerance (% passing) | | | | | | | Asphalt (avg. %) |
|---|---|---|---|---|---|---|---|---|
| | 1½-In. | 1-In. | ½-In. | No. 4 | No. 10 | No. 40 | No. 200 | |
| F-1 surface | | | 100 | 75-90 | 60-80 | 15-35 | 2-10 | 7.0 |
| F-4 surface | | | | 100 | 95-100 | 40-95 | 2-8 | 9.0 |
| I-3 surface | | | 100 | 50-70 | 35-50 | 10-25 | 2-10 | 6.2 |
| H-2 binder | | 100 | | 40-60 | 30-40 | | | 5.5 |
| H-3 (1) base | 90-100 | | | 30-45 | 20-35 | | 0-5 | 4.5 |
| F-2 base (local) | | 100 | 85-100 | 75-100 | 60-95 | 20-50 | 0-10 | 4.5 |

Compaction Requirements.—Compaction of completed pavements generally required to produce density not less than 90 percent of the calculated density of voidless mixture composed of same materials in like proportions. Exceptions made for local sand mixes of types F-2 and F-3; density requirements less rigid.

## Aggregate Base and Subbase Materials

| Material | Gradation Tolerance (% passing) | | | | | |
|---|---|---|---|---|---|---|
| | 2-In. | 1-In. | 3/8-In. | No. 10 | No. 40 | No. 200 |
| Base grading A | 100 | 50-80 | 30-65 | 15-40 | 10-20 | 4-10 |
| Base grading B | 100 | 65-90 | 50-75 | 25-45 | 12-30 | 4-15 |
| Base grading C | 100 | 90-100 | 50-85 | 25-50 | 12-30 | 5-15 |
| Base grading D | | 100 | 60-100 | 30-65 | 20-40 | 5-15 |
| Base grading E | | 100 | | 40-100 | 20-50 | 6-20 |
| Base grading F | | 100 | | 55-100 | 30-70 | 8-25 |
| Subbase grading 1 | 100 | 80-100 | 50-90 | 30-70 | 10-40 | 4-15 |
| Subbase grading 2 | 100 | - | - | 40-100 | 25-75 | 0-25 |

Type I Base Material.—Crushed stone, slag, or gravel, maximum liquid limit 25, maximum P. I. 3, grading A, B, C, or D.

Type II Base Material.—Maximum liquid limit 25, maximum P. I. 6, grading C, D, E, or F.

Type III Base Material (Graded Aggregate).—Crushed stone, slag, or gravel premixed with soil mortar fraction in pug mill or other approved plant. Grading B only, otherwise same as Type I.

Subbase Materials.—Maximum liquid limit 25, maximum P. I. 3.

Los Angeles abrasion loss on plus No. 10 fraction.—45 percent maximum, all base types.

Compaction Requirements.—Compaction of completed base or subbase required to produce density not less than 100 percent of the maximum theoretical density "D" calculated as described in paper "Suggested Compaction Standards for Crushed Aggregate Materials Based on Experimental Field Rolling," by F. P. Nichols, Jr., and H. D. James, HRB Bull. 325 (1962). Modified standards suggested in above paper not applicable to any of the pavements in this report.

## Select Materials

Required properties variable from job to job, specified in Special Provisions attached to individual contracts. Typical requirements:

Maximum aggregate size—3 in.
Maximum passing the No. 200 sieve—25-40 percent.
Maximum liquid limit—25-40.
Maximum laboratory CBR—10-30.
Compaction requirements same as for bases and subbases.

## Stabilized Subgrades or Subbases

Granular materials or friable soils generally stabilized with cement; percentages 5 to 12 percent by volume. Heavy clays stabilized with hydrated lime, usually 5 to 6 percent. Layer thicknesses usually 6 in. compacted, maximum 8 in. in friable soil. Compaction of completed stabilized layer required to produce density of 100 percent of the density of the same material when tested in accordance with AASHO Method T-134, with tolerance of 5 pcf.