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Monument Valley Freeway, Interstate Route 25, in Colorado Springs, Colo.

IN THIS ISSUE:

A discussion of properties of highway asphalts.

A new O-D survey technique—*continuous sampling.*

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*Cover picture courtesy of Colorado State Highway Department*

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**U.S. DEPARTMENT OF COMMERCE**
**FREDERICK H. MUELLER, Secretary**

**BUREAU OF PUBLIC ROADS**
**BERTRAM D. TALLAMY, Administrator**
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# Properties of Highway Asphalts—Part II, Various Penetration Grades

*BY THE DIVISION OF PHYSICAL RESEARCH*
*BUREAU OF PUBLIC ROADS*

**Reported[1] by J. YORK WELBORN, Chief, Bituminous and Chemical Branch, WOODROW J. HALSTEAD, Head, Bituminous Materials and Chemical Section, and J. GAYLOID BOONE, Analytical Chemist**

***This article is the second in a general study of asphalt cements produced in the United States for highway construction. A total of 323 samples from 105 refineries were received and tested. Results of the tests on 146 samples of the 85–100 penetration grade were reported in the first article, part I.[2] This article, part II, includes the results of the tests on the other penetration grades—namely, the 60–70 grade asphalts, the 70–85 grade, 120–150 grade, and 150–200 grade asphalts. Comparisons of the characteristics of several grades including the 85–100 grade reported in part I are also included.***

***These data establish the range for test values that may be expected for asphalts on a nationwide basis. The significance of the wide differences existing in materials meeting the same specifications, and the need for further research to establish more adequate test methods and specifications, are discussed in the article.***

IN 1954, a comprehensive study of asphalts was undertaken by the Division of Physical Research to provide current data on a national scale that would show the properties of asphalt produced from the various crude sources and by the different methods of refining in current use in the United States. The samples were obtained by the regional offices of the Bureau of Public Roads with the full cooperation of the States and refineries in each area of the Nation.

Nearly all producers supplying asphalt for the study included samples in the 85–100 penetration grade. Since this group was considered the most representative of all asphalt cements produced and used, it was selected for the initial study. The results of those tests were reported in Public Roads as part I of the extensive study.[2] This article, part II, presents the results of the tests made on the other penetration grades.

A total of 323 samples were received during 1954 and 1955 from 105 refineries or storage terminals. Of these, 146 were in the 85–100 penetration grade which was reported in part I. This report includes the results of tests on the following asphalt cements: 60–70 grade, 58 samples; 70–85 grade, 30; 120–150 grade, 60; and 150–200 grade, 16 samples.

It may be noted that the numbers of samples tested in each grade differ slightly from the numbers given in the first report. This is due to the elimination of a few samples because of the lack of proper identification of their origin. Also, since only 7 samples of the 100–120 grade were received, they have been omitted from the discussion.

Data in this report, as in the earlier report, include only those test characteristics in general use as specification requirements or those that are being used by some agencies in an effort to obtain better materials. All testing was performed according to ASTM or AASHO standard methods of test.

Tables 1 through 4 show the results of the tests for the 60–70, 70–85, 120–150, and 150–200 penetration grades, respectively. In each table refineries are identified by code number, the same number applying to the same refinery for all grades. To avoid possible confusion in sample identification all samples are numbered consecutively beginning at 120. Numbers 1–119 were those used for the 85–100 grade reported in part I.

Tables 1 through 4 also include information on the crude source and method of refining used to produce the asphalt cements. Although in many cases more precise information as to the geographical location of the crude sources and details of methods of refining were provided, only general terms are given in this report.

The 85–100 grade materials reported previously represent the majority of the samples submitted and is the grade most widely produced and used. In the earlier report of this penetration grade, frequency distribution graphs in the form of frequency polygons were used to show the range in properties. This report, part II, presents the data in a similar manner and directly compares the test results for the 60–70, 85–100, and 120–150 penetration grades. Since the number of asphalts received varied for the different grades, the percent of samples was used for the unit of the vertical axis rather than the actual number of samples. The percentages of values in each class interval were then plotted at the midpoint of the respective class interval and connected to form the polygon. Values exactly equal to the limit dividing two class intervals are included with the upper interval. Where they are believed to be significant, median values for the test results are shown on the graphs for purposes of comparison.

The data used for the graphs are the test values given in table 1 (for 47 of the 60–70 asphalts), table 3 (for 56 of the 120–150 asphalts), and table 1 of part I (for 119 samples of 85–100 penetration grade asphalts). Sample identification numbers appearing in tables 1 and 3 having a suffix a, b, or x represent duplications of materials from the same refinery and the tests values for these materials were not included in the analysis. It is recognized that the difference in representation of the number and source of samples in each grade may have some influence on the distribution polygons. However, since the samples were submitted as being representative of the asphalts used in the various States, the graphs should be generally indicative of properties of the available asphalts of these grades. Because the number of samples tested in the 70–85 grade and the 150–200 grade are limited and represent only a relatively small portion of the asphalts used in only a few areas of the Nation, they are not included in this analysis. However, the test data given in tables 2 and 4 should be of interest in those areas where such asphalts are used.

In order to obtain a direct comparison of the properties of the asphalt cements of different penetration grades from the same refinery source, some of the test data shown in tables 1–4 of this report and in table 1 of part I are repeated in table 5. The samples selected for this comparison are asphalt cements of three or more grades refined from the same crude

[1] This article was presented at the Association of Asphalt Paving Technologists, Memphis, Tenn., January 1960.

[2] *Properties of highway asphalts—part I, 85–100 penetration grade*, J. York Welborn and Woodrow J. Halstead, Public Roads, Vol. 30, No. 9, Aug. 1959, pp. 197–207.

## Table 1.—Test characteristics of 60–70 penetration grade asphalts

| B.P.R. region [1] | Sample identification [2] | Source of crude | Method of refining [3] | Penetration: 100 g., 5 sec. at 77° F. | Penetration: 200 g., 60 sec. at 39.2° F. | Penetration: Penetration ratio, 39.2°/77° F. | Ductility: 5 cm. per minute 77° F. | Ductility: 1 cm. per minute 39.2° F. | Softening point | Furol viscosity at 275° F. | Specific gravity at 77° F. | Flash point: Pensky-Martens closed cup | Flash point: Cleveland open cup | Soluble in $CCl_4$ | Standard oven test at 325° F., 5 hours: Loss [4] | Standard oven test: Penetration of residue: Value | Standard oven test: Penetration of residue: Percent of original | Thin-film oven test, ⅛-inch film at 325° F., 5 hours: Loss [4] | Thin-film: Tests on residue: Softening point | Thin-film: Tests on residue: Ductility, 5 cm. per min., 77° F. | Thin-film: Tests on residue: Penetration at 77° F. | Thin-film: Tests on residue: Percent of original penetration |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | *Cm.* | *Cm.* | *°F.* | *Sec.* | | *°F.* | *°F.* | *Pct.* | *Pct.* | | | *Pct.* | *°F.* | *Cm.* | | |
| Region 1 | 120 (2) | Venezuela | V, S | 66 | 24 | 36 | 250+ | 9.5 | 124 | 283 | 1.032 | 500 | 540 | 99.73 | 0.03 | 59 | 89 | 0.10 | 133 | 168 | 42 | 64 |
| | 121 (22) | Mexico | S | 57 | 25 | 44 | 250+ | 11.3 | 128 | 431 | 1.039 | 480 | 545 | 99.84 | .06 | 52 | 91 | .29 | 140 | 100 | 37 | 65 |
| | 122 (30) | Colombia | | 64 | 22 | 34 | 187 | 10.0 | 121 | 247 | 1.011 | 500 | 640 | 99.57 | .04 | 58 | 91 | +.07 | 129 | 250+ | 47 | 73 |
| | 123 (32) | Venezuela | V | 53 | 28 | 53 | 250+ | 6.0 | 131 | 342 | 1.018 | 490 | 565 | 99.84 | .02 | 48 | 91 | .07 | 142 | 47 | 35 | 66 |
| | 124 (77) | Venezuela, Texas | V, S, O | 64 | 25 | 39 | 228 | 8.0 | 122 | 295 | 1.021 | 435 | 580 | 99.75 | .18 | 53 | 83 | .45 | 135 | 162 | 37 | 58 |
| | 125 (86) | Gulf Coast | V | 62 | 25 | 40 | 250+ | 8.3 | 123 | 267 | 1.015 | 530 | 600 | 99.86 | .00 | 55 | 89 | .00 | 132 | 223 | 45 | 73 |
| | 126 (90) | | | 52 | 22 | 42 | 250+ | 8.8 | 126 | 279 | 1.021 | 480 | 560 | 99.87 | .07 | 48 | 92 | .18 | 135 | 218 | 38 | 73 |
| Region 2 | 127 (1) | | | 64 | 23 | 36 | 250+ | 9.8 | 122 | 358 | 1.035 | 495 | 540 | 99.75 | .01 | 57 | 89 | .05 | 133 | 183 | 42 | 66 |
| | 128 (3) | Venezuela | V, S | 60 | 25 | 42 | 250+ | 8.5 | 125 | 346 | 1.033 | 475 | 515 | 99.68 | .09 | 51 | 85 | .36 | 139 | 140 | 37 | 62 |
| | 129 (9) | do | S | 64 | 23 | 36 | 215 | 24.0 | 126 | 347 | 1.038 | 455 | 505 | 99.80 | .10 | 56 | 88 | .46 | 137 | 113 | 38 | 59 |
| | 130 (14) | | | 60 | 20 | 33 | 250+ | 10.5 | 122 | 213 | 1.024 | 500 | 575 | 99.92 | .01 | 54 | 90 | .00 | 131 | 250+ | 40 | 67 |
| | 131 (17) | | | 61 | 32 | 52 | 61 | 4.5 | 135 | 337 | .993 | 415 | 625 | 99.74 | .06 | 55 | 90 | .08 | 146 | 11 | 44 | 72 |
| | 132 (31) | Venezuela, Mississippi | V | 60 | 19 | 32 | 250+ | 10.0 | 121 | 222 | 1.024 | 575 | 585 | 99.91 | .00 | 55 | 92 | .01 | 129 | 250+ | 39 | 65 |
| | 133 (70) | | | 70 | 27 | 39 | 246 | 16.3 | 121 | 254 | 1.020 | 480 | 575 | 99.80 | .03 | 60 | 86 | .07 | 130 | 250+ | 46 | 66 |
| | 134 (82) | | | 67 | 27 | 40 | 174 | 6.8 | 125 | 262 | .995 | 540 | 630 | 99.82 | .01 | 58 | 87 | +.05 | 136 | 115 | 46 | 69 |
| | 134a (82) | | | 59 | 25 | 42 | 196 | 5.5 | 128 | 292 | .996 | 540 | 635 | 99.85 | +.01 | 54 | 92 | +.04 | 138 | 81 | 43 | 73 |
| | 135 (109) | | | 59 | 27 | 46 | 147 | 5.3 | 129 | 339 | 1.010 | 545 | 615 | 99.85 | .00 | 53 | 90 | .05 | 138 | 39 | 42 | 71 |
| Region 3 | 136 (10) | Venezuela, Mexico | S | 62 | 25 | 40 | 250+ | 13.2 | 126 | 365 | 1.038 | 450 | 515 | 99.83 | .09 | 56 | 90 | .44 | 132 | 137 | 38 | 61 |
| | 137 (11) | Texas | S, V | 55 | 23 | 42 | 250 | 7.3 | 127 | 293 | 1.033 | 440 | 580 | 99.82 | .10 | 48 | 87 | .14 | 136 | 143 | 35 | 64 |
| | 138 (33) | Venezuela | S, V | 59 | 20 | 38 | 250+ | 9.5 | 124 | 272 | 1.024 | 495 | 580 | 99.77 | .04 | 51 | 86 | .10 | 132 | 250+ | 38 | 64 |
| Region 4 | 139 (1) | do | V | 63 | 21 | 33 | 200 | 14.5 | 125 | 321 | 1.035 | 495 | 515 | 99.84 | .05 | 58 | 92 | .20 | 134 | 201 | 40 | 63 |
| | 139a (1) | do | V | 61 | 24 | 39 | 250+ | 10.0 | 126 | 327 | 1.035 | 500 | 530 | 99.81 | .03 | 54 | 89 | .06 | 135 | 182 | 39 | 64 |
| | 140 (7) | Texas | V | 62 | 24 | 39 | 233 | 7.3 | 123 | 300 | 1.034 | 490 | 590 | 99.86 | .03 | 55 | 89 | .09 | 133 | 231 | 41 | 66 |
| | 140a (7) | do | V | 61 | 20 | 33 | 250+ | 5.5 | 125 | 341 | 1.031 | 500 | 600 | 99.88 | .01 | 58 | 95 | .01 | 138 | 62 | 42 | 69 |
| | 141 (8) | Midcontinent | V, O | 67 | 25 | 37 | 87 | 3.8 | 129 | 236 | .996 | 515 | 640 | 99.83 | .03 | 59 | 88 | .02 | 137 | 44 | 46 | 69 |
| | 142 (13) | | | 57 | 20 | 35 | 250+ | 5.3 | 125 | 247 | 1.004 | 580 | 690 | 99.78 | .00 | 49 | 86 | +.06 | 130 | 172 | 37 | 65 |
| | 143 (31) | | V, S | 62 | 23 | 37 | 250+ | 10.3 | 122 | 238 | 1.024 | 530 | 580 | 99.80 | .00 | 54 | 87 | +.09 | 129 | 250+ | 44 | 66 |
| | 144 (45) | Wyoming | V | 62 | 20 | 32 | 203 | 6.8 | 123 | 205 | 1.026 | 490 | 630 | 99.76 | .01 | 53 | 86 | +.06 | 129 | 250+ | 39 | 63 |
| | 145 (46) | Arkansas | V, S | 55 | 21 | 38 | 250+ | 4.5 | 126 | 293 | 1.019 | 585 | 665 | 99.79 | .00 | 50 | 91 | +.09 | 132 | 183 | 41 | 75 |
| | 146 (59) | Texas, Wyoming | S, O | 60 | 23 | 38 | 133 | 6.5 | 123 | 195 | 1.029 | 500 | 580 | 99.70 | .03 | 52 | 87 | .06 | 133 | 188 | 38 | 63 |
| | 146a (59) | do | S, O | 60 | 25 | 41 | 235 | 6.3 | 124 | 241 | 1.014 | 505 | 600 | 99.90 | .06 | 57 | 93 | .08 | 133 | 228 | 42 | 69 |
| | 146b (59) | do | S, O | 57 | 22 | 39 | 198 | 5.5 | 125 | 209 | 1.023 | 505 | 585 | 99.83 | .03 | 51 | 89 | .04 | 133 | 165 | 38 | 64 |
| | 147 (67) | Texas | V, O | 59 | 18 | 31 | 228 | 4.8 | 123 | 185 | 1.017 | 505 | 610 | 99.87 | .04 | 52 | 88 | .10 | 130 | 218 | 37 | 63 |
| | 148 (70) | Venezuela | S, V, B | 58 | 25 | 43 | 218 | 11.8 | 126 | 277 | 1.020 | 510 | 585 | 99.81 | .02 | 54 | 93 | .04 | 133 | 172 | 41 | 71 |
| | 149 (73) | Wyoming, Oklahoma | V | 66 | 24 | 36 | 225 | 7.0 | 119 | 190 | 1.016 | 475 | 625 | 99.86 | .05 | 55 | 83 | .05 | 129 | 250+ | 41 | 62 |
| | 150 (89) | Midcontinent | V, O | 60 | 25 | 42 | 223 | 6.3 | 127 | 268 | 1.000 | 540 | 650 | 99.84 | .01 | 55 | 92 | +.05 | 133 | 208 | 44 | 73 |
| | 151 (93) | Wyoming | V | 63 | 28 | 44 | 241 | 6.5 | 129 | 213 | 1.030 | 480 | 585 | 99.75 | .04 | 49 | 78 | .04 | 133 | 250+ | 35 | 56 |
| | 152 (94) | Midcontinent, Wyoming | V, S, O | 64 | 17 | 27 | 218 | 2.8 | 121 | 178 | 1.014 | 565 | 630 | 99.82 | .01 | 58 | 91 | +.08 | 126 | 250+ | 45 | 70 |
| | 139x (1) | Venezuela | | 60 | 22 | 37 | 250+ | 13.0 | 126 | 351 | 1.038 | 500 | 525 | 99.92 | .02 | 54 | 90 | .08 | 136 | 237 | 38 | 63 |
| | 140x (7) | Texas | | 64 | 28 | 42 | 170 | 6.5 | 128 | 349 | 1.032 | 470 | 585 | 99.78 | .04 | 57 | 89 | .03 | 141 | 45 | 42 | 66 |
| | 144x (45) | Wyoming | | 65 | 21 | 32 | 250+ | 9.0 | 121 | 205 | 1.027 | 375 | 615 | 99.93 | .13 | 54 | 83 | .08 | 131 | 250+ | 38 | 58 |
| | 145x (46) | Arkansas | | 60 | 20 | 33 | 250+ | 5.0 | 123 | 293 | 1.025 | 555 | 675 | 99.94 | .00 | 53 | 88 | +.07 | 134 | 250+ | 41 | 68 |
| | 146x (59) | Texas | | 59 | 25 | 42 | 250+ | 7.0 | 122 | 251 | 1.013 | 480 | 585 | 99.79 | .06 | 53 | 90 | .00 | 131 | 230 | 41 | 69 |
| | 151x (93) | Wyoming | | 63 | 18 | 29 | 246 | 8.5 | 125 | 217 | 1.029 | 460 | 600 | 99.92 | .05 | 52 | 83 | .00 | 132 | 250+ | 36 | 57 |
| Region 6 | 153 (7) | Texas | V | 67 | 26 | 39 | 203 | 8.3 | 125 | 288 | 1.033 | 480 | 585 | 99.65 | .04 | 59 | 88 | .07 | 132 | 203 | 42 | 63 |
| | 154 (23) | do | V, S | 63 | 16 | 25 | 212 | 6.0 | 122 | 144 | 1.033 | 530 | 600 | 99.73 | .01 | 56 | 89 | +.04 | 127 | 176 | 39 | 62 |
| | 155 (27) | Midcontinent | V, S, O | 60 | 22 | 37 | 250+ | 5.8 | 124 | 253 | 1.005 | 535 | 630 | 99.80 | .00 | 55 | 92 | +.01 | 131 | 181 | 40 | 67 |
| | 156 (35) | Texas | V, S | 67 | 27 | 40 | 170 | 6.5 | 125 | 343 | 1.030 | 550 | 615 | 99.56 | .01 | 62 | 93 | +.09 | 135 | 64 | 46 | 69 |
| | 157 (41) | do | P, O | 61 | 18 | 30 | 250+ | 7.3 | 120 | 210 | .999 | 575 | 650 | 99.79 | +.01 | 57 | 93 | +.09 | 124 | 245 | 46 | 75 |
| | 158 (46) | Wyoming | V, S, B | 56 | 22 | 39 | 250+ | 5.8 | 126 | 304 | 1.020 | 580 | 670 | 99.87 | .01 | 54 | 96 | +.08 | 133 | 157 | 41 | 73 |
| | 159 (48) | Oklahoma | V, O | 66 | 40 | 61 | 62 | 5.3 | 134 | 373 | 1.003 | 400 | 485 | 99.81 | .15 | 62 | 94 | .68 | 147 | 10 | 44 | 67 |
| | 160 (49) | Arkansas | V, S, B, O | 59 | 28 | 47 | 237 | 5.3 | 128 | 356 | 1.017 | 560 | 630 | 99.88 | .00 | 55 | 93 | +.06 | 137 | 54 | 43 | 73 |
| | 161 (54) | Mississippi | S | 62 | 34 | 55 | 142 | 5.5 | 131 | 379 | 1.034 | 495 | 525 | 99.94 | .06 | 54 | 87 | .25 | 144 | 37 | 40 | 65 |
| | 162 (57) | Gulf Coast, Midcontinent. | V, P, O | 68 | 24 | 35 | 210 | 4.8 | 124 | 165 | 1.006 | 515 | 605 | 99.65 | .04 | 63 | 93 | .12 | 129 | 165 | 48 | 71 |
| | 163 (65) | Mississippi | S | 62 | 26 | 42 | 172 | 5.8 | 129 | 366 | 1.032 | 475 | 520 | 99.72 | .06 | 52 | 84 | .17 | 142 | 65 | 39 | 63 |
| | 164 (87) | Gulf Coast | V | 62 | 26 | 42 | 209 | 8.5 | 121 | 245 | 1.034 | 535 | 600 | 99.82 | +.01 | 56 | 90 | +.02 | 134 | 131 | 41 | 66 |
| | 165 (104) | Oklahoma | V, S | 61 | 26 | 43 | 242 | 7.5 | 127 | 256 | 1.016 | 475 | 565 | 99.81 | .00 | 52 | 85 | .03 | 130 | 74 | 40 | 66 |
| | 166 (111) | Arkansas | V | 53 | 24 | 45 | 204 | 7.5 | 127 | 337 | 1.027 | 540 | 630 | 99.67 | .00 | 48 | 91 | .01 | 134 | 181 | 38 | 72 |

[1] For States included in each of the Bureau of Public Roads regions, see inside front cover. No samples of 60–70 grade asphalts received from regions 5, 7, 8, and 9.
[2] Numbers in parentheses indicate refinery code number.
[3] V=vacuum distillation, S=steam distillation, O=blowing (oxidation), B=blending (different grades of asphalt), P=propane fractionation, and F=fluxing (heavy oils).
[4] Plus values represent gains rather than losses.

## Table 2.—Test characteristics of 70–85 penetration grade asphalts

| B.P.R. region[1] | Sample identification[2] | Source of crude | Method of refining[3] | Penetration: 100 g., 5 sec. at 77° F. | Penetration: 200 g., 60 sec. at 39.2° F. | Penetration: Penetration ratio, 39.2°/77° F. | Ductility: 5 cm. per minute 77° F. | Ductility: 1 cm. per minute 39.2° F. | Softening point | Furol viscosity at 275° F. | Specific gravity at 77° F. | Flash point: Pensky-Martens closed cup | Flash point: Cleveland open cup | Soluble in $CCl_4$ | Standard oven test at 325° F., 5 hours: Loss | Standard oven test: Penetration of residue: Value | Standard oven test: Penetration of residue: Percent of original | Thin-film oven test, 1/8-inch film at 325° F., 5 hours: Loss[4] | Thin-film: Tests on residue: Softening point | Thin-film: Tests on residue: Ductility, 5 cm. per min., 77° F. | Thin-film: Tests on residue: Penetration at 77° F. | Thin-film: Tests on residue: Percent of original penetration |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Cm. | Cm. | °F. | Sec. | | °F. | °F. | Pct. | Pct. | | | Pct. | °F. | Cm. | | |
| Region 2 | 167 (82) | | | 67 | 27 | 40 | 174 | 6.8 | 125 | 240 | 0.995 | 540 | 630 | 99.82 | 0.01 | 58 | 87 | +0.05 | 136 | 115 | 46 | 69 |
| | 168 (88) | Gulf Coast | V | 71 | 31 | 44 | 250+ | 10.8 | 123 | 222 | 1.024 | 500 | 575 | 99.83 | .03 | 64 | 90 | .09 | 132 | 178 | 48 | 68 |
| Region 4 | 169 (7) | Texas | V | 66 | 26 | 39 | 243 | 8.3 | 125 | 266 | 1.038 | 475 | 570 | 99.87 | .07 | 57 | 86 | .21 | 133 | 250+ | 41 | 62 |
| | 170 (8) | Midcontinent | V, O | 73 | 28 | 38 | 111 | 5.8 | 123 | 175 | .996 | 540 | 625 | 99.83 | .03 | 71 | 97 | .03 | 130 | 58 | 55 | 75 |
| | 171 (15) | Wyoming | V | 73 | 25 | 34 | 207 | 13.3 | 120 | 176 | 1.028 | 495 | 595 | 99.85 | .03 | 65 | 89 | .05 | 128 | 250+ | 45 | 62 |
| | 172 (19) | Louisiana, Wyoming | V | 74 | 30 | 41 | 173 | 7.0 | 121 | 199 | .995 | 430 | 690 | 99.92 | .01 | 68 | 92 | .06 | 125 | 170 | 59 | 80 |
| | 173 (27) | Midcontinent | S, V, O | 82 | 27 | 33 | 174 | 9.3 | 118 | 210 | 1.023 | 420 | 650 | 99.80 | .11 | 71 | 87 | .17 | 129 | 202 | 49 | 60 |
| | 174 (43) | Wyoming | V | 72 | 25 | 35 | 190 | 11.3 | 121 | 158 | 1.031 | 480 | 585 | 99.84 | .03 | 62 | 86 | +.02 | 128 | 186 | 45 | 63 |
| | 175 (47) | Canada | V | 79 | 18 | 23 | 179 | 7.8 | 115 | 110 | 1.009 | 540 | 615 | 99.93 | .00 | 67 | 85 | +.07 | 125 | 177 | 47 | 60 |
| | 176 (59) | Wyoming, Texas | S, O | 72 | 29 | 40 | 110 | 7.3 | 121 | 153 | 1.019 | 500 | 550 | 99.91 | .03 | 65 | 90 | .08 | 132 | 170 | 45 | 63 |
| | 177 (60) | Midcontinent | S, V, O | 71 | 33 | 46 | 107 | 5.5 | 125 | 270 | .999 | 495 | 625 | 99.74 | .02 | 63 | 89 | .01 | 137 | 33 | 48 | 68 |
| | 178 (64) | Wyoming, Texas | V, O | 82 | 28 | 34 | 187 | 7.5 | 118 | 173 | 1.004 | 515 | 630 | 99.84 | .01 | 71 | 87 | +.04 | 127 | 189 | 54 | 66 |
| | 178a (64) | do | V, B, O | 75 | 25 | 33 | 198 | 6.5 | 120 | 158 | 1.010 | 580 | 630 | 99.81 | .01 | 67 | 89 | +.08 | 126 | 222 | 51 | 68 |
| | 179 (67) | Texas | V, O | 64 | 21 | 33 | 192 | 6.3 | 119 | 176 | 1.016 | 480 | 600 | 99.90 | .04 | 56 | 88 | .08 | 127 | 250+ | 39 | 61 |
| | 180 (74) | Wyoming, Oklahoma | V | 66 | 24 | 36 | 225 | 7.0 | 119 | 245 | 1.016 | 475 | 625 | 99.86 | .05 | 55 | 83 | .05 | 129 | 250+ | 41 | 62 |
| | 181 (78) | Kansas | S, V, B | 72 | 28 | 39 | 189 | 5.5 | 124 | 192 | 1.007 | 470 | 605 | 99.79 | .04 | 63 | 88 | .07 | 133 | 34 | 44 | 61 |
| | 182 (81) | | | 72 | 34 | 47 | 211 | 6.5 | 125 | 206 | 1.012 | 545 | 610 | 99.78 | .00 | 66 | 92 | +.06 | 135 | 76 | 51 | 71 |
| | 183 (89) | Midcontinent | V, O | 69 | 31 | 45 | 167 | 7.5 | 123 | 253 | .994 | 540 | 630 | 99.88 | .02 | 64 | 93 | +.01 | 133 | 146 | 52 | 75 |
| | 184 (91) | Wyoming | V | 75 | 28 | 37 | 250+ | 9.3 | 121 | 199 | 1.019 | 525 | 610 | 99.73 | .01 | 63 | 84 | .01 | 129 | 250+ | 47 | 63 |
| | 185 (93) | Midcontinent, Wyoming. | S, V, B | 75 | 26 | 35 | 174 | 9.3 | 119 | 175 | 1.012 | 465 | 610 | 99.81 | .07 | 69 | 92 | .11 | 126 | 167 | 51 | 68 |
| | 186 (94) | do | S, V, B, O | 63 | 19 | 30 | 250+ | 7.3 | 120 | 176 | 1.014 | 530 | 630 | 99.82 | .00 | 51 | 81 | +.09 | 128 | 207 | 43 | 68 |
| | 187 (96) | Wyoming | V, O | 82 | 33 | 40 | 160 | 30.5 | 120 | 205 | 1.023 | 475 | 520 | 99.86 | .07 | 73 | 89 | .32 | 131 | 167 | 49 | 60 |
| Region 5 | 188 (20) | Midcontinent | V | 65 | 24 | 37 | 100 | 5.0 | 126 | 208 | 1.002 | 450 | 695 | 99.81 | .00 | 59 | 91 | .03 | 139 | 14 | 45 | 69 |
| | 189 (25) | Kansas | V | 89 | 36 | 40 | 153 | 7.0 | 120 | 222 | .999 | 435 | 665 | 99.70 | .03 | 82 | 92 | .01 | 131 | 62 | 59 | 66 |
| | 190 (55) | Kansas, Oklahoma, Texas. | V, P, B | 70 | 26 | 37 | 206 | 8.3 | 119 | 233 | 1.004 | 565 | 660 | 99.87 | .00 | 64 | 91 | +.03 | 129 | 183 | 49 | 70 |
| | 191 (61) | Texas, Wyoming, Midcontinent. | V, O, P | 66 | 29 | 44 | 218 | 7.5 | 123 | 192 | 1.029 | 505 | 550 | 99.81 | .04 | 58 | 88 | .13 | 133 | 162 | 41 | 62 |
| | 192 (68) | Texas | V, O | 69 | 21 | 30 | 195 | 7.3 | 121 | 180 | 1.015 | 505 | 610 | 99.64 | .04 | 62 | 90 | .06 | 124 | 225 | 44 | 64 |
| | 193 (74) | Wyoming, Oklahoma | V | 69 | 22 | 32 | 241 | 9.0 | 120 | 189 | 1.014 | 540 | 620 | 99.88 | .01 | 62 | 90 | +.03 | 128 | 228 | 44 | 64 |
| | 194 (87) | Texas | V, B, O | 71 | 31 | 44 | 250+ | 8.3 | 121 | 228 | 1.015 | 505 | 590 | 99.89 | .00 | 64 | 90 | .00 | 132 | 160 | 47 | 66 |
| | 195 (111) | Arkansas | V, S | 73 | 29 | 40 | 237 | 20.8 | 120 | 249 | 1.024 | 540 | 630 | 99.81 | .02 | 66 | 90 | +.02 | 127 | 250+ | 52 | 71 |

[1] For States included in each of the Bureau of Public Roads regions, see inside front cover. No samples of 70–85 grade asphalts received from regions 1, 3, 6, 7, 8, and 9.
[2] Number in parentheses indicate refinery code number.
[3] V=vacuum distillation, S=steam distillation, O=blowing (oxidation), B=blending (different grades of asphalt), P=propane fractionation, and F=fluxing (heavy oils).
[4] Plus values represent gains rather than losses.

## Table 3.—Test characteristics of 120–150 penetration grade asphalts

| B.P.R. region[1] | Sample identification[2] | Source of crude | Method of refining[3] | Penetration | | | Ductility | | Softening point | Furol viscosity at 275° F. | Specific gravity at 77° F. | Flash point | | Soluble in $CCl_4$ | Standard oven test at 325° F., 5 hours | | | Thin-film oven test, ⅛-inch film at 325° F., 5 hours | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 100 g., 5 sec. at 77° F. | 200 g., 60 sec. at 39.2° F. | Penetration ratio, 39.2°/77° F. | 5 cm. per minute at 77° F. | 1 cm. per minute at 39.2° F. | | | | Pensky-Martens closed cup | Cleveland open cup | | Loss[4] | Penetration of residue: Value | Penetration of residue: Percent of original | Loss[4] | Tests on residue: Softening point | Tests on residue: Ductility, 5 cm per min., 77° F. | Tests on residue: Penetration at 77° F. | Tests on residue: Percent of original penetration |
| | | | | | | | Cm. | Cm. | °F. | Sec. | | °F. | °F. | Pct. | Pct. | | | Pct. | °F. | Cm. | | |
| Region 1 | 196 (22) | Mexico | S | 135 | 61 | 45 | 184 | 250+ | 113 | 250 | 1.034 | 430 | 495 | 99.67 | 0.22 | 111 | 82 | 0.93 | 129 | 235 | 68 | 50 |
| | 197 (22) | do | S | 131 | 47 | 36 | 229 | 96 | 110 | 246 | 1.029 | 430 | 490 | 99.72 | .26 | 103 | 79 | 1.12 | 129 | 186 | 61 | 47 |
| | 198 (30) | Colombia | | 132 | 45 | 34 | 132 | 124 | 108 | 156 | .999 | 500 | 635 | 99.74 | .01 | 111 | 84 | +.06 | 114 | 120 | 88 | 67 |
| | 199 (77) | Venezuela, Texas | V, S | 128 | 45 | 33 | 141 | 182 | 110 | 152 | 1.018 | 405 | 530 | 99.68 | .24 | 110 | 86 | .73 | 119 | 229 | 72 | 56 |
| Region 2 | 200 (1) | | | 142 | 55 | 39 | 162 | 173 | 110 | 175 | 1.030 | 455 | 490 | 99.74 | .10 | 120 | 85 | .54 | 123 | 190 | 73 | 51 |
| | 201 (3) | Venezuela | V, S | 127 | 46 | 36 | 182 | 250+ | 111 | 158 | 1.026 | 425 | 475 | 99.59 | .21 | 105 | 83 | 1.10 | 123 | 192 | 62 | 49 |
| | 202 (9) | do | S | 135 | 54 | 40 | 185 | 173 | 111 | 231 | 1.030 | 420 | 500 | 99.82 | .27 | 112 | 83 | 1.18 | 123 | 213 | 64 | 47 |
| | 203 (14) | | | 128 | 47 | 37 | 172 | 250+ | 108 | 125 | 1.020 | 495 | 550 | 99.71 | .03 | 113 | 88 | .10 | 117 | 227 | 79 | 62 |
| | 204 (17) | | | 126 | 51 | 40 | 145 | 15.5 | 112 | 163 | .989 | 410 | 640 | 99.62 | .07 | 118 | 94 | .02 | 123 | 114 | 75 | 60 |
| | 205 (31) | Venezuela | | 135 | 53 | 39 | 190 | 135 | 109 | 146 | 1.014 | 480 | 555 | 99.75 | .02 | 115 | 85 | .02 | 119 | 210 | 82 | 61 |
| | 206 (70) | | | 121 | 50 | 41 | 218 | 232 | 109 | 160 | 1.015 | 495 | 575 | 99.73 | .03 | 107 | 88 | .04 | 119 | 250+ | 76 | 63 |
| Region 4 | 207 (1) | Venezuela | V, S | 138 | 50 | 36 | 200 | 173 | 111 | 188 | 1.028 | 470 | 485 | 99.73 | .10 | 130 | 94 | .58 | 122 | 240 | 74 | 54 |
| | 207a (1) | do | V, S | 132 | 47 | 36 | 147 | 154 | 111 | 190 | 1.029 | 475 | 500 | 99.72 | .09 | 115 | 87 | .53 | 122 | 217 | 72 | 55 |
| | 208 (8) | Midcontinent | V, O | 152 | 40 | 26 | 87 | 10 | 108 | 105 | .992 | 510 | 655 | 99.75 | .04 | 143 | 94 | .04 | 115 | 126 | 91 | 60 |
| | 209 (13) | Illinois | S, V | 130 | 38 | 29 | 141 | 41 | 110 | 128 | 1.003 | 465 | 620 | 99.70 | .04 | 107 | 82 | .03 | 120 | 160 | 72 | 55 |
| | 210 (51) | Wyoming | V | 128 | 44 | 34 | 138 | 250+ | 110 | 111 | 1.026 | 485 | 555 | 99.78 | .04 | 111 | 87 | .06 | 118 | 185 | 74 | 58 |
| | 211 (59) | Wyoming, Texas | S, O | 151 | 49 | 34 | 97 | 56.5 | 108 | 93 | 1.017 | 500 | 550 | 99.58 | .03 | 126 | 83 | .05 | 116 | 133 | 86 | 57 |
| | 211a (59) | do | S, O | 121 | 42 | 35 | 141 | 67.5 | 111 | 122 | 1.018 | 500 | 560 | 99.89 | .02 | 104 | 87 | .04 | 119 | 191 | 72 | 60 |
| | 212 (60) | Midcontinent | S, V, O | 142 | 48 | 34 | 110 | 12.5 | 109 | 136 | .995 | 550 | 640 | 99.61 | .01 | 118 | 83 | +.07 | 119 | 164 | 84 | 59 |
| | 213 (64) | Wyoming, Texas | V | 136 | 36 | 26 | 148 | 48.5 | 108 | 106 | 1.010 | 495 | 610 | 99.77 | .13 | 110 | 81 | .15 | 117 | 162 | 73 | 54 |
| | 213a (64) | do | V | 138 | 35 | 25 | 125 | 58.5 | 107 | 110 | 1.011 | 475 | 630 | 99.78 | .01 | 112 | 81 | +.07 | 116 | 180 | 77 | 56 |
| | 214 (67) | Texas | V, O | 138 | 36 | 26 | 124 | 45 | 113 | 107 | 1.010 | 440 | 605 | 99.73 | .09 | 115 | 83 | .10 | 117 | 163 | 76 | 55 |
| | 215 (89) | Midcontinent | V, O | 117 | 41 | 35 | 128 | 75.5 | 113 | 135 | .993 | 545 | 630 | 99.83 | .02 | 108 | 92 | +.02 | 122 | 125 | 83 | 71 |
| | 216 (94) | Midcontinent, Wyoming | S, V, O | 143 | 40 | 28 | 115 | 31 | 109 | 121 | .999 | 470 | 625 | 99.76 | .05 | 124 | 87 | .01 | 116 | 146 | 87 | 61 |
| | 216a (94) | do | S, V, O | 138 | 49 | 36 | 85 | 13.8 | 110 | 124 | .993 | 540 | 625 | 99.71 | .01 | 123 | 89 | .06 | 117 | 98 | 93 | 67 |
| | 217 (96) | Wyoming | V, O | 133 | 46 | 35 | 118 | 84 | 111 | 146 | 1.021 | 455 | 520 | 99.67 | .09 | 114 | 86 | .27 | 119 | 145 | 76 | 57 |
| Region 5 | 218 (38) | do | V | 135 | 45 | 33 | 141 | 117 | 110 | 113 | 1.021 | 390 | 565 | 99.68 | .12 | 108 | 80 | .17 | 119 | 229 | 71 | 53 |
| | 219 (43) | do | V | 152 | 53 | 35 | 155 | 132 | 106 | 97 | 1.026 | 380 | 555 | 99.90 | .11 | 119 | 78 | .24 | 117 | 240 | 77 | 51 |
| | 220 (51) | do | S, V | 125 | 44 | 35 | 155 | 182 | 110 | 123 | 1.025 | 500 | 580 | 99.69 | .03 | 107 | 86 | .05 | 120 | 234 | 71 | 57 |
| | 221 (52) | do | S, F | 120 | 50 | 42 | 144 | 250+ | 110 | 128 | 1.028 | 360 | 665 | 99.77 | .19 | 102 | 85 | .27 | 121 | 204 | 67 | 56 |
| | 222 (79) | do | V, S, B | 130 | 33 | 25 | 141 | 22 | 110 | 105 | 1.019 | 425 | 615 | 99.68 | .07 | 108 | 83 | .06 | 117 | 173 | 73 | 56 |
| | 223 (96) | do | V, O | 126 | 48 | 38 | 125 | 250+ | 111 | 145 | 1.022 | 470 | 535 | 99.61 | .07 | 110 | 87 | .23 | 121 | 150 | 74 | 59 |
| Region 6 | 224 (7) | Texas | V | 121 | 44 | 36 | 170 | 135 | 112 | 187 | 1.024 | 500 | 580 | 99.72 | .00 | 112 | 93 | .02 | 122 | 182 | 73 | 60 |
| | 225 (21) | do | V, O, B, F | 132 | 41 | 31 | 122 | 11.8 | 109 | 109 | 1.023 | 485 | 580 | 99.71 | .04 | 110 | 83 | .08 | 120 | 115 | 68 | 52 |
| | 226 (23) | do | S, V | 126 | 37 | 29 | 118 | 68.5 | 109 | 86 | 1.023 | 500 | 570 | 98.82 | .02 | 112 | 89 | .01 | 118 | 120 | 72 | 57 |
| | 227 (27) | Midcontinent | S, V | 127 | 37 | 29 | 150 | 14.3 | 109 | 150 | 1.000 | 445 | 655 | 99.61 | .05 | 102 | 80 | .09 | 118 | 154 | 77 | 61 |
| | 228 (35) | Texas | S, V | 140 | 58 | 41 | 154 | 26.5 | 113 | 156 | 1.021 | 520 | 585 | 99.76 | .00 | 112 | 80 | +.04 | 124 | 109 | 83 | 59 |
| | 229 (41) | do | P, O | 130 | 29 | 22 | 126 | 94 | 109 | 167 | .988 | 535 | 645 | 99.75 | .00 | 114 | 88 | +.06 | 113 | 145 | 90 | 69 |
| | 230 (46) | Arkansas | S, V | 122 | 40 | 33 | 173 | 17.8 | 111 | 166 | 1.014 | 585 | 655 | 99.60 | +.01 | 112 | 92 | +.09 | 117 | 215 | 80 | 66 |
| | 231 (48) | Oklahoma | V, O | 141 | 68 | 48 | 195 | 20.3 | 113 | 165 | 1.001 | 430 | 485 | 99.74 | .17 | 123 | 87 | .74 | 127 | 91 | 78 | 55 |
| | 232 (49) | Arkansas | S, V | 140 | 48 | 34 | 142 | 250+ | 109 | 174 | 1.013 | 580 | 630 | 99.64 | +.01 | 125 | 89 | +.12 | 117 | 175 | 92 | 66 |
| | 233 (54) | Mississippi | S | 125 | 67 | 54 | 177 | 20.5 | 116 | 180 | 1.026 | 415 | 500 | 99.82 | .16 | 96 | 77 | .63 | 133 | 90 | 62 | 50 |
| | 234 (57) | Gulf, Midcontinent | V, B, O | 140 | 48 | 34 | 109 | 9.3 | 109 | 95 | .995 | 485 | 585 | 99.95 | .07 | 122 | 87 | .15 | 122 | 93 | 84 | 60 |
| | 235 (65) | Mississippi | S, B | 127 | 61 | 48 | 166 | 34.5 | 114 | 186 | 1.025 | 410 | 510 | 99.74 | .11 | 106 | 83 | .41 | 127 | 111 | 70 | 55 |
| | 236 (72) | Texas, Kansas | V, P, B | 125 | 33 | 26 | 146 | 6.3 | 114 | 213 | .981 | 590 | 655 | 99.66 | +.01 | 119 | 95 | +.04 | 119 | 87 | 83 | 64 |
| | 237 (85) | Gulf, Mexico | V | 121 | 40 | 33 | 135 | 250+ | 111 | 94 | 1.023 | 500 | 525 | 99.59 | .01 | 118 | 98 | .13 | 114 | 130 | 84 | 69 |
| | 238 (87) | Gulf Coast | V | 128 | 44 | 34 | 157 | 144 | 110 | 169 | 1.020 | 540 | 590 | 99.76 | .00 | 112 | 88 | .04 | 119 | 250+ | 83 | 65 |
| | 239 (92) | Texas | V, O | 129 | 47 | 37 | 142 | 250+ | 106 | 72 | 1.009 | 455 | 515 | 99.69 | .07 | 119 | 92 | .37 | 111 | 217 | 100 | 78 |
| | 240 (95) | do | S, V, O | 137 | 52 | 38 | 135 | 40 | 109 | 120 | .998 | 475 | 600 | 99.73 | .04 | 114 | 83 | .03 | 119 | 164 | 80 | 58 |
| | 241 (97) | Oklahoma | V | 130 | 38 | 29 | 110 | 133 | 112 | 166 | 1.017 | 470 | 690 | 99.75 | .01 | 116 | 89 | .07 | 115 | 165 | 83 | 64 |
| | 242 (104) | do | S, V | 120 | 44 | 37 | 158 | 19.8 | 111 | 136 | 1.010 | 485 | 560 | 99.70 | .01 | 102 | 85 | .01 | 122 | 195 | 71 | 59 |
| | 243 (106) | do | V, B | 134 | 44 | 33 | 205 | 12.3 | 112 | 157 | .990 | 390 | 660 | 99.83 | .06 | 112 | 84 | .05 | 121 | 162 | 76 | 57 |
| | 244 (111) | Arkansas | V | 127 | 51 | 40 | 170 | 99 | 110 | 181 | 1.020 | 550 | 650 | 99.78 | .01 | 118 | 93 | .00 | 116 | 169 | 87 | 69 |
| | 245 (111) | do | V | 127 | 47 | 37 | 138 | 23.5 | 111 | 141 | 1.019 | 535 | 615 | 99.71 | .02 | 112 | 88 | +.05 | 120 | 183 | 77 | 61 |
| | 246 (24) | California | S, V | 130 | 52 | 40 | 175 | 82 | 111 | 145 | 1.024 | 430 | 470 | 99.74 | .18 | 120 | 92 | .98 | 123 | 250+ | 70 | 54 |
| | 247 (40) | do | V, B, O | 136 | 42 | 31 | 135 | 250+ | 104 | 71 | 1.005 | 470 | 525 | 99.71 | .06 | 124 | 91 | .14 | 111 | 137 | 93 | 68 |
| | 248 (58) | do | S, V | 122 | 41 | 34 | 158 | 232 | 110 | 103 | 1.015 | 460 | 510 | 99.84 | .10 | 104 | 85 | .11 | 117 | 159 | 70 | 57 |
| | 249 (66) | do | S, V, B | 124 | 44 | 33 | 193 | 250 | 110 | 72 | 1.012 | 500 | 545 | 99.84 | .04 | 110 | 89 | .20 | 113 | 200 | 79 | 64 |
| | 250 (99) | do | S, F | 121 | 44 | 36 | 166 | 77 | 112 | 160 | 1.027 | 440 | 480 | 99.88 | .14 | 100 | 83 | 1.02 | 130 | 115 | 57 | 47 |
| | 251 (112) | do | S, V | 141 | 50 | 35 | 188 | 157 | 109 | 155 | 1.029 | 420 | 470 | 99.85 | .22 | 109 | 77 | 1.43 | 129 | 175 | 59 | 42 |

[1] For States included in each of the Bureau of Public Roads regions, see inside front cover. No samples of 120–150 grade asphalts received from regions 3, 7, 8, and 9.
[2] Numbers in parentheses indicate code designation of refinery.
[3] V=vacuum distillation, S=steam distillation, O=blowing (oxidation), B=blending (different grades of asphalt), P=propane fractionation, and F=fluxing (heavy oils).
[4] Plus values represent gains rather than losses.

## Table 4.—Test characteristics of 150–200 penetration grade asphalts

| B.P.R. region [1] | Sample identification [2] | Source of crude | Method of refining [3] | Penetration: 100 g., 5 sec. at 77° F. | Penetration: 200 g., 60 sec. at 39.2° F. | Penetration: Penetration ratio, 39.2°/77° F. | Ductility: 5 cm. per minute at 77° F. | Ductility: 1 cm. per minute at 39.2° F. | Softening point | Furol viscosity at 275° F. | Specific gravity at 77° F. | Flash point: Pensky-Martens closed cup | Flash point: Cleveland open cup | Soluble in CCl4 | Standard oven test at 325° F., 5 hours: Loss [4] | Standard oven test: Penetration of residue: Value | Standard oven test: Penetration of residue: Percent of original | Thin-film oven test, 1/8-inch film at 325° F., 5 hours: Loss [4] | Thin-film: Tests on residue: Softening point | Thin-film: Tests on residue: Ductility, 5 cm. per min., 77° F. | Thin-film: Tests on residue: Penetration at 77° F. | Thin-film: Tests on residue: Percent of original penetration |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Cm. | Cm. | °F. | Sec. | | °F. | °F. | Pct. | Pct. | | | Pct. | °F. | Cm. | | |
| Region 3 | 252 (6) | Venezuela, Mississippi | S, V, B | 153 | 58 | 38 | 167 | 200+ | 107 | 164 | 1.028 | 440 | 475 | 99.71 | 0.15 | 135 | 88 | 0.76 | 122 | 156 | 78 | 50 |
| | 253 (10) | Venezuela, Mexico | S | 189 | 81 | 43 | 147 | 200+ | 107 | 173 | 1.031 | 415 | 460 | 99.65 | .33 | 147 | 78 | 1.48 | 125 | 178 | 78 | 41 |
| | 254 (11) | Texas | S, F | 175 | 68 | 39 | 133 | 200+ | 106 | 136 | 1.022 | 355 | 555 | 99.64 | .24 | 141 | 81 | .57 | 117 | 225 | 85 | 48 |
| | 255 (33) | Venezuela | S, V | 181 | 70 | 39 | 119 | 200+ | 104 | 122 | 1.015 | 495 | 545 | 99.67 | .04 | 154 | 85 | .12 | 115 | 175 | 101 | 56 |
| | 256 (42) | Mississippi | S, V | 182 | 68 | 37 | 105 | 200+ | 106 | 135 | 1.026 | 435 | 515 | 99.73 | .08 | 147 | 81 | .30 | 115 | 156 | 100 | 55 |
| | 257 (63) | do. | S | 158 | 85 | 54 | 142 | 134 | 109 | 149 | 1.024 | 415 | 480 | 99.74 | .20 | 132 | 84 | .86 | 127 | 140 | 76 | 48 |
| | 258 (69) | Venezuela | B | 173 | 65 | 38 | 160 | 200+ | 103 | 114 | 1.015 | 505 | 555 | 99.71 | .02 | 152 | 88 | .02 | 111 | 218 | 109 | 63 |
| | 259 (83) | Mississippi | S, V | 165 | 71 | 43 | 133 | 102 | 107 | 146 | 1.029 | 460 | 505 | 99.72 | .15 | 154 | 93 | .29 | 120 | 185 | 91 | 55 |
| | 259a (83) | do. | S, V | 161 | 66 | 41 | 148 | 35 | 107 | 119 | 1.002 | 480 | 595 | 99.85 | .03 | 137 | 85 | .04 | 120 | 129 | 96 | 60 |
| | 260 (102) | do. | S | 166 | 87 | 52 | 144 | 127 | 108 | 148 | 1.023 | 395 | 475 | 99.74 | .30 | 131 | 79 | 1.16 | 128 | 154 | 73 | 42 |
| | 261 (103) | do. | S | 162 | 85 | 52 | 120 | 15 | 109 | 252 | 1.021 | 425 | 490 | 99.91 | .23 | 137 | 85 | .98 | 127 | 158 | 79 | 49 |
| Region 5 | 262 (18) | Wyoming | V | 193 | 65 | 34 | 112 | 200+ | 101 | 79.4 | 1.022 | 325 | 610 | 99.73 | .45 | 137 | 71 | .60 | 115 | 165 | 83 | 43 |
| Region 8 | 263 (16) | ---- | ---- | 151 | 30 | 20 | 146 | ---- | 104 | ---- | 1.068 | 420 | 500 | 99.47 | .22 | 124 | 82 | .73 | 116 | 200 | 65 | 43 |
| | 264 (18) | Wyoming | V | 164 | 43 | 26 | 150 | 40 | 106 | 83.0 | 1.022 | 590 | 625 | 99.72 | +.03 | 134 | 82 | +.12 | 113 | 123 | 94 | 57 |
| | 265 (26) | ---- | ---- | 151 | 57 | 38 | 94 | 44 | 110 | 114 | 1.024 | 390 | 470 | 99.81 | .37 | 123 | 81 | 1.17 | 127 | 77 | 65 | 43 |
| | 266 (38) | ---- | ---- | 176 | 54 | 31 | 89 | 200+ | 102 | 95.2 | 1.028 | 465 | 560 | 99.81 | .06 | 147 | 84 | .04 | 115 | 178 | 87 | 49 |

[1] For States included in each of the Bureau of Public Roads regions, see inside front cover. No samples of 150–200 grade asphalts received from regions 1, 2, 4, 6, 7, and 9.
[2] Numbers in parentheses indicate code designation refinery.
[3] V = vacuum distillation, S = steam distillation, O = blowing (oxidation), B = blending (different grades of asphalt), P = propane fractionation, and F = fluxing (heavy oils).
[4] Plus values represent gains rather than losses.

## Table 5.—Test characteristics of asphalts of different grades from same refinery source

| Sample identification [1] | Grade | Source of crude | Method of refining [2] | Penetration: 100 g., 5 sec. at 77° F. | Penetration: Penetration ratio, 39.2°/77° F. | Ductility: 5 cm. per minute at 77° F. | Ductility: 1 cm. per minute at 39.2° F. | Softening point | Furol viscosity at 275° F. | Specific gravity at 77° F. | Flash point: Pensky-Martens closed cup | Flash point: Cleveland open cup | Thin-film oven test, ⅛-inch film at 325° F., 5 hours: Loss [3] | Tests on residue: Softening point | Tests on residue: Ductility, 5 cm. per min., at 77° F. | Tests on residue: Percent of original penetration |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cm. | Cm. | ° F. | Sec. | | ° F. | ° F. | Pct. | ° F. | Cm. | |
| 127 (1) | 60–70 | Venezuela | V, S | 64 | 36 | 250+ | 9.8 | 122 | 358 | 1.035 | 495 | 540 | 0.05 | 133 | 183 | 66 |
| 13 | 85–100 | | V, S | 89 | 36 | 175 | 18.3 | 120 | 255 | 1.033 | 480 | 530 | .18 | 132 | 175 | 62 |
| 200 | 120–150 | | V, S | 142 | 39 | 162 | 173 | 110 | 175 | 1.030 | 455 | 490 | .54 | 123 | 190 | 51 |
| 128 (3) | 60–70 | Venezuela | V, S | 60 | 42 | 250+ | 8.5 | 125 | 346 | 1.033 | 475 | 515 | .36 | 139 | 140 | 62 |
| 14 | 85–100 | | V, S | 92 | 35 | 185 | 20.5 | 117 | 232 | 1.030 | 440 | 490 | .70 | 130 | 182 | 57 |
| 201 | 120–150 | | V, S | 127 | 36 | 182 | 250+ | 111 | 158 | 1.026 | 425 | 475 | 1.10 | 123 | 192 | 49 |
| 153 (7) | 60–70 | Texas | V | 67 | 39 | 203 | 8.3 | 125 | 288 | 1.033 | 480 | 585 | .07 | 132 | 203 | 63 |
| 169 | 70–85 | | V | 66 | 39 | 243 | 8.3 | 125 | 266 | 1.038 | 475 | 570 | .21 | 133 | 250+ | 62 |
| 67 | 85–100 | | V | 90 | 38 | 201 | 20.8 | 122 | 243 | 1.029 | 460 | 575 | .08 | 129 | 192 | 61 |
| 224 | 120–150 | | V | 121 | 36 | 170 | 135 | 112 | 187 | 1.024 | 500 | 580 | .02 | 122 | 182 | 60 |
| 141 (8) | 60–70 | Midcontinent | V, O | 67 | 37 | 87 | 3.8 | 129 | 236 | .996 | 515 | 640 | .02 | 137 | 44 | 69 |
| 170 | 70–85 | | V, O | 73 | 38 | 111 | 5.8 | 123 | 175 | .996 | 540 | 625 | .03 | 130 | 58 | 75 |
| 38 | 85–100 | | V, O | 90 | 36 | 170 | 6.3 | 120 | 189 | 1.000 | 510 | 605 | .00 | 129 | 120 | 62 |
| 208 | 120–150 | | V, O | 152 | 26 | 87 | 10.0 | 108 | 105 | .992 | 510 | 655 | .04 | 115 | 126 | 60 |
| 129 (9) | 60–70 | Venezuela | S | 64 | 36 | 215 | 24.0 | 126 | 347 | 1.038 | 455 | 505 | .46 | 137 | 113 | 59 |
| 15 | 85–100 | | S | 96 | 35 | 189 | 33.5 | 118 | 249 | 1.036 | 420 | 490 | .64 | 132 | 176 | 55 |
| 202 | 120–150 | | S | 135 | 40 | 185 | 173 | 111 | 231 | 1.030 | 420 | 500 | 1.18 | 123 | 213 | 47 |
| 130 (14) | 60–70 | | | 60 | 33 | 250+ | 10.5 | 122 | 213 | 1.024 | 500 | 575 | .00 | 131 | 250+ | 67 |
| 17 | 85–100 | | | 93 | 37 | 196 | 63 | 116 | 166 | 1.022 | 535 | 565 | +.04 | 123 | 205 | 66 |
| 203 | 120–150 | | | 128 | 37 | 172 | 250+ | 108 | 125 | 1.020 | 495 | 550 | .10 | 117 | 227 | 62 |
| 131 (17) | 60–70 | | | 61 | 52 | 61 | 4.5 | 135 | 337 | .993 | 415 | 625 | .08 | 146 | 11 | 72 |
| 18 | 85–100 | | | 87 | 46 | 116 | 7.3 | 124 | 239 | .992 | 425 | 630 | .08 | 135 | 29 | 66 |
| 204 | 120–150 | | | 126 | 40 | 145 | 15.5 | 112 | 163 | .989 | 410 | 640 | .02 | 123 | 114 | 60 |
| 121 (22) | 60–70 | Mexico | S | 57 | 44 | 250+ | 11.3 | 128 | 431 | 1.039 | 480 | 545 | .29 | 140 | 100 | 65 |
| 3 | 85–100 | | S | 87 | 45 | 248 | 51.5 | 121 | 318 | 1.037 | 445 | 500 | .55 | 134 | 138 | 60 |
| 196 | 120–150 | | S | 135 | 45 | 184 | 250+ | 113 | 250 | 1.034 | 430 | 495 | .93 | 129 | 235 | 50 |
| 154 (23) | 60–70 | Texas | V, S | 63 | 25 | 212 | 6.0 | 122 | 144 | 1.033 | 530 | 600 | .04 | 127 | 176 | 62 |
| 69 | 85–100 | | V, S | 87 | 23 | 112 | 12.5 | 116 | 120 | 1.029 | 535 | 585 | +.02 | 125 | 178 | 61 |
| 226 | 120–150 | | V, S | 126 | 29 | 118 | 68.5 | 109 | 86 | 1.023 | 500 | 570 | .01 | 118 | 120 | 57 |
| 155 (27) | 60–70 | Midcontinent | V, S, O | 60 | 37 | 250+ | 5.8 | 124 | 253 | 1.005 | 535 | 630 | +.01 | 131 | 181 | 67 |
| 70 | 85–100 | | V, S | 87 | 32 | 150 | 6.8 | 120 | 208 | 1.005 | 570 | 635 | +.03 | 127 | 250+ | 61 |
| 227 | 120–150 | | V, S | 127 | 29 | 150 | 14.3 | 109 | 150 | 1.000 | 445 | 655 | .09 | 118 | 154 | 61 |
| 122 (30) | 60–70 | Colombia | | 64 | 34 | 187 | 10.0 | 121 | 247 | 1.011 | 500 | 640 | +.07 | 129 | 250+ | 73 |
| 6 | 85–100 | | | 86 | 35 | 180 | 30.5 | 115 | 200 | 1.005 | 525 | 580 | +.10 | 122 | 250+ | 71 |
| 198 | 150–200 | | | 132 | 34 | 132 | 124 | 108 | 156 | .999 | 500 | 635 | +.06 | 114 | 120 | 67 |
| 138 (33) | 60–70 | Venezuela | V, S | 59 | 38 | 250+ | 9.5 | 124 | 272 | 1.024 | 495 | 580 | .10 | 132 | 250+ | 64 |
| 27 | 85–100 | | V, S | 93 | 37 | 195 | 88 | 113 | 153 | 1.025 | 495 | 545 | .13 | 123 | 221 | 66 |
| 255 | 150–200 | | V, S | 181 | 39 | 119 | 200+ | 104 | 122 | 1.015 | 495 | 545 | .12 | 115 | 175 | 56 |
| 156 (35) | 60–70 | Texas | V, S | 67 | 40 | 170 | 6.5 | 125 | 343 | 1.030 | 550 | 615 | +.09 | 135 | 64 | 69 |
| 73 | 85–100 | | V, S | 93 | 35 | 234 | 10.3 | 116 | 239 | 1.025 | 465 | 625 | .05 | 125 | 209 | 64 |
| 228 | 120–150 | | V, S | 140 | 41 | 154 | 26.5 | 113 | 156 | 1.021 | 520 | 585 | +.04 | 124 | 109 | 59 |
| 157 (41) | 60–70 | do | P, O | 61 | 30 | 250+ | 7.3 | 120 | 210 | .999 | 575 | 650 | +.09 | 124 | 245 | 75 |
| 74 | 85–100 | | V, P, O | 94 | 23 | 250+ | 4.3 | 117 | 263 | 1.005 | 525 | 640 | +.03 | 127 | 181 | 68 |
| 229 | 120–150 | | P, O | 130 | 22 | 126 | 94 | 109 | 167 | .998 | 535 | 645 | +.06 | 113 | 145 | 69 |
| 159 (48) | 60–70 | Oklahoma | V, O | 66 | 61 | 62 | 5.3 | 134 | 373 | 1.003 | 400 | 485 | .68 | 147 | 10 | 67 |
| 76 | 85–100 | | V, O | 93 | 52 | 107 | 7.5 | 125 | 257 | 1.002 | 425 | 475 | .70 | 138 | 20 | 61 |
| 231 | 120–150 | | V, O | 141 | 48 | 195 | 20.3 | 113 | 165 | 1.001 | 430 | 485 | .74 | 127 | 91 | 55 |
| 160 (49) | 60–70 | Arkansas | V, S, B, O | 59 | 47 | 237 | 5.3 | 128 | 356 | 1.017 | 560 | 630 | +.06 | 137 | 54 | 73 |
| 77 | 85–100 | | V, S, B, O | 94 | 37 | 213 | 9.8 | 117 | 238 | 1.016 | 550 | 635 | .06 | 124 | 185 | 69 |
| 232 | 120–150 | | V, S | 140 | 34 | 142 | 250+ | 109 | 174 | 1.013 | 580 | 630 | +.12 | 117 | 175 | 66 |
| 161 (54) | 60–70 | Mississippi | S | 62 | 55 | 142 | 5.5 | 131 | 379 | 1.034 | 495 | 525 | .25 | 144 | 37 | 65 |
| 78 | 85–100 | | S | 92 | 52 | 139 | 9.3 | 122 | 240 | 1.030 | 400 | 490 | .42 | 138 | 36 | 58 |
| 233 | 120–150 | | S | 125 | 54 | 177 | 20.5 | 116 | 180 | 1.026 | 415 | 500 | .63 | 133 | 90 | 50 |
| 162 (57) | 60–70 | Gulf Coast, Midcontinent. | V, P, O | 68 | 35 | 210 | 4.8 | 124 | 165 | 1.006 | 515 | 605 | .12 | 129 | 165 | 71 |
| 79 | 85–100 | | V, P, O, B | 90 | 26 | 145 | 6.0 | 118 | 123 | 1.001 | 485 | 565 | .20 | 127 | 114 | 70 |
| 234 | 120–150 | | V, O, B | 140 | 34 | 109 | 9.3 | 109 | 95 | .995 | 485 | 585 | .15 | 122 | 93 | 60 |
| 146 (59) | 60–70 | Texas, Wyoming | S, O | 60 | 38 | 133 | 6.5 | 123 | 195 | 1.029 | 500 | 580 | .06 | 133 | 188 | 63 |
| 47a | 85–100 | | S, O | 88 | 32 | 202 | 24.0 | 118 | 160 | 1.021 | 515 | 575 | .03 | 126 | 190 | 59 |
| 211a | 120–150 | | S, O | 121 | 35 | 141 | 67.5 | 111 | 122 | 1.018 | 500 | 560 | .04 | 119 | 191 | 60 |
| 163 (65) | 60–70 | Mississippi | S | 62 | 42 | 172 | 5.8 | 129 | 366 | 1.032 | 475 | 520 | .17 | 142 | 65 | 63 |
| 80 | 85–100 | | S | 90 | 52 | 180 | 17.0 | 114 | 246 | 1.030 | 445 | 520 | .20 | 128 | 102 | 63 |
| 235 | 120–150 | | S, B | 127 | 48 | 166 | 34.5 | 114 | 186 | 1.025 | 410 | 510 | .41 | 127 | 111 | 55 |
| 147 (67) | 60–70 | Texas | V, O | 59 | 31 | 228 | 4.8 | 123 | 185 | 1.017 | 505 | 610 | .10 | 130 | 248 | 63 |
| 179 | 70–85 | | V, O | 64 | 33 | 192 | 6.3 | 119 | 176 | 1.016 | 480 | 600 | .08 | 127 | 250+ | 61 |
| 50 | 85–100 | | V, O, B | 98 | 30 | 140 | 8.0 | 114 | 135 | 1.015 | 435 | 610 | .09 | 125 | 166 | 52 |
| 214 | 120–150 | | V, O | 138 | 26 | 124 | 45.0 | 113 | 107 | 1.010 | 440 | 605 | .10 | 117 | 163 | 55 |
| 124 (77) | 60–70 | Venezuela and Texas | S, V, O | 64 | 39 | 228 | 8.0 | 122 | 295 | 1.021 | 435 | 580 | .45 | 135 | 162 | 58 |
| 9 | 85–100 | | S, V, O | 93 | 38 | 150 | 22.3 | 116 | 198 | 1.022 | 415 | 540 | .50 | 130 | 226 | 57 |
| 199 | 120–150 | | S, V | 128 | 33 | 141 | 182 | 110 | 152 | 1.018 | 405 | 530 | .73 | 119 | 229 | 56 |
| 164 (87) | 60–70 | Gulf Coast | V | 62 | 42 | 209 | 8.5 | 121 | 245 | 1.034 | 535 | 600 | +.02 | 134 | 131 | 66 |
| 23 | 85–100 | | V | 81 | 46 | 190 | 11.3 | 119 | 198 | 1.016 | 530 | 585 | .04 | 127 | 208 | 70 |
| 238 | 120–150 | | V | 128 | 34 | 157 | 144 | 110 | 169 | 1.020 | 540 | 590 | .04 | 119 | 250+ | 65 |
| 150 (89) | 60–70 | Midcontinent | V, O | 60 | 42 | 223 | 6.3 | 127 | 268 | 1.000 | 540 | 650 | +.05 | 133 | 208 | 73 |
| 183 | 70–85 | | V, O | 69 | 45 | 167 | 7.5 | 123 | 253 | .994 | 540 | 630 | +.01 | 133 | 146 | 75 |
| 53 | 85–100 | | V, O | 86 | 40 | 151 | 7.3 | 119 | 195 | .995 | 545 | 635 | +.03 | 126 | 150 | 69 |
| 215 | 120–150 | | V, O | 117 | 35 | 128 | 75.5 | 113 | 135 | .993 | 545 | 630 | +.02 | 122 | 125 | 71 |
| 165 (104) | 60–70 | Oklahoma | V, S | 61 | 43 | 242 | 7.5 | 127 | 256 | 1.016 | 475 | 565 | .03 | 130 | 74 | 66 |
| 87 | 85–100 | | V, S | 88 | 39 | 166 | 12.3 | 118 | 180 | 1.012 | 515 | 570 | +.05 | 128 | 162 | 63 |
| 242 | 120–150 | | V, S | 120 | 37 | 158 | 19.8 | 111 | 136 | 1.010 | 485 | 560 | .01 | 122 | 195 | 59 |
| 166 (111) | 60–70 | Arkansas | V, S | 53 | 45 | 204 | 7.5 | 127 | 337 | 1.027 | 540 | 630 | .01 | 134 | 181 | 72 |
| 195 | 70–85 | | V, S | 73 | 40 | 237 | 20.8 | 120 | 249 | 1.024 | 540 | 630 | +.02 | 127 | 250+ | 71 |
| 89 | 85–100 | | V, S | 89 | 34 | 138 | 11.0 | 116 | 236 | 1.021 | 560 | 660 | .09 | 124 | 160 | 72 |
| 244 | 120–150 | | V, S | 127 | 40 | 170 | 99.0 | 110 | 181 | 1.020 | 550 | 650 | .00 | 116 | 169 | 69 |

[1] Numbers in parentheses indicate refinery code number. [2] V=vacuum distillation, S=steam distillation, O=blowing (oxidation), B=blending (different grades of asphalt), P=propane fractionation, and F=fluxing (heavy oils). [3] Plus values represent gains rather than losses.

source or combination of sources by a specific refinery and are assumed to represent concurrent production.

## Results of Tests

The following discussion of the frequency distribution graphs for the 60–70, 85–100, and 120–150 penetration grades points out the range and variations in some of the test characteristics. The relation of the penetration grades to the changes in some of the test characteristics are also discussed.

**Penetration at 77° F.**

Figure 1 shows the range and distribution of the results of the penetration test at 77° F. for the three grades. Thirteen, or approximately 28 percent, of the 47 samples of the 60–70 asphalts had penetration values of less than 60; none exceeded the upper limit of 70. In part I, 12 samples, or approximately 10 percent, of the 85–100 grade had values below 85; and, there also, none exceeded the upper limit of 100. Of the 56 asphalts of the 120–150 grade, 1 sample was less than 120 and 3 exceeded 150, which constituted about 7 percent of the samples. There is a general trend for the median value for all of these grades to approach the lower limit of the specification rather than the upper. The medians were 62, 89, and 130 for the respective grades.

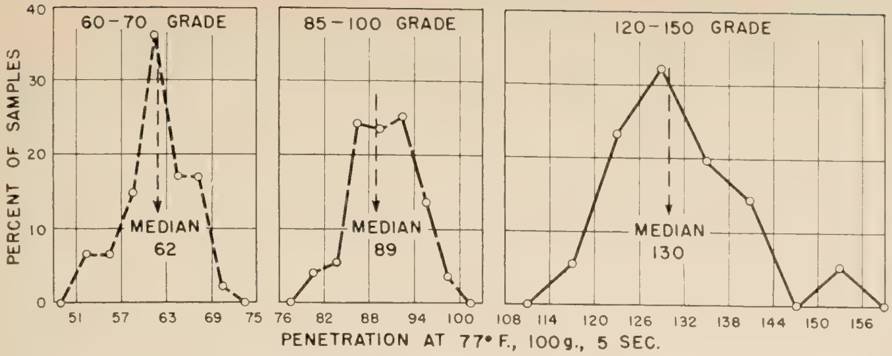


*Figure 1.—Distribution of penetration.*

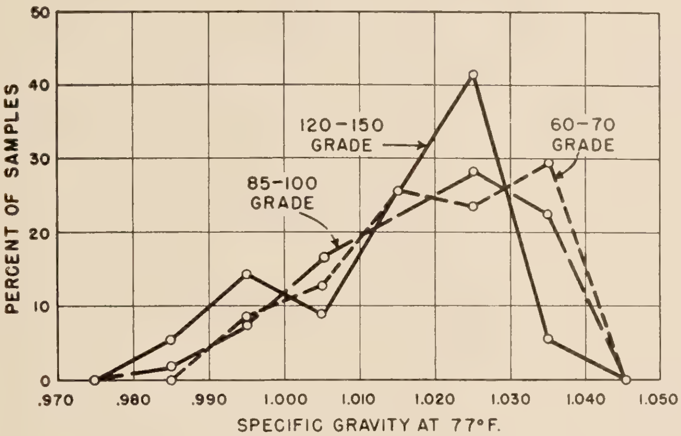


*Figure 2.—Distribution of specific gravity.*

**Specific gravity at 77° F.**

The specific gravity of asphalt cements is seldom used as a specification requirement, but it is often needed to establish design criteria for bituminous mixtures. It may also be used to control the uniformity of the supply of asphalt from a refinery for a specific project. The general distribution data plotted in figure 2, indicate that the differences in the overall range of specific gravities for the three grades were not significant. The effect of penetration on specific gravity is better illustrated in figure 3 where some of the data given in table 5 are plotted to show the relation between these characteristics for the various grades of asphalt from the same sources. These graphs also show that for materials from the same source the specific

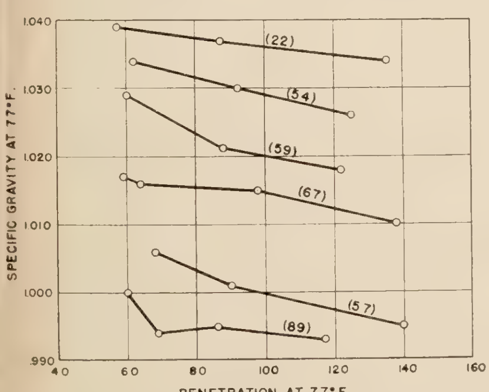


*Figure 3.—Relation of penetration at 77° F. to specific gravity at 77° F.*

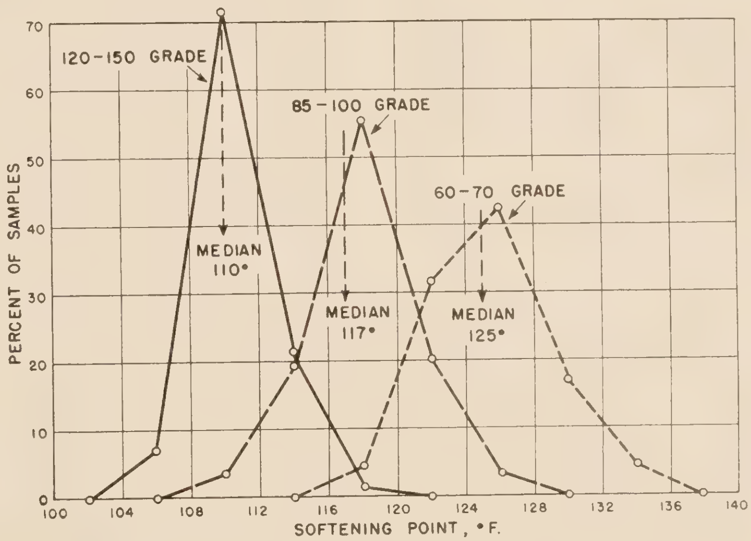


*Figure 4.—Distribution of softening points.*

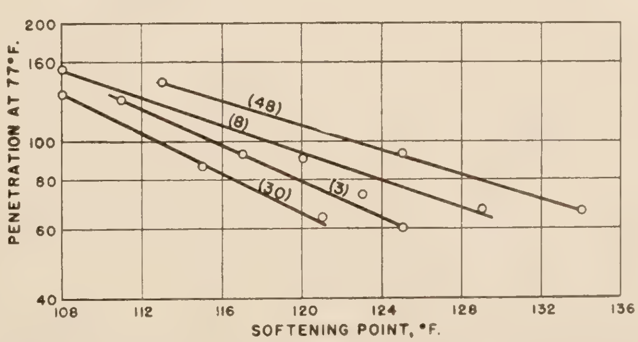


*Figure 5.—Relation of penetration at 77° F. to softening point.*

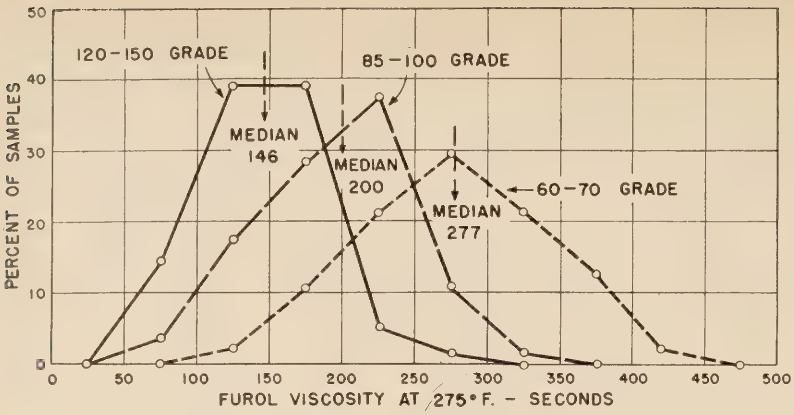


*Figure 6.—Distribution of Furol viscosity.*

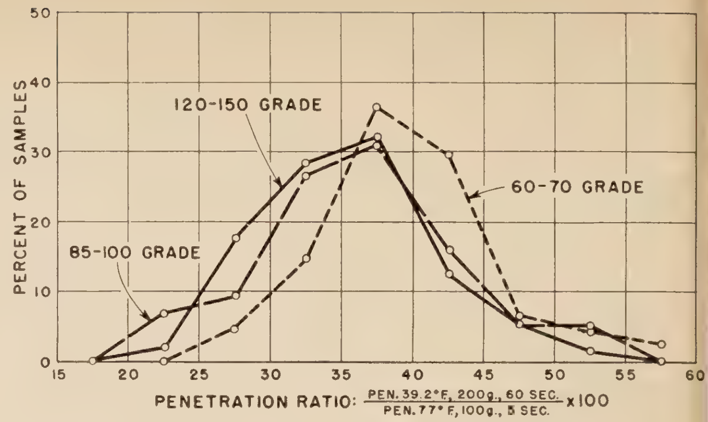


*Figure 8.—Distribution of penetration ratios.*

gravity decreased slightly as the penetration increased. (*Note:* The numbers in parentheses shown in this figure and subsequent figures illustrating the relation of penetration to other properties are the refinery code numbers.)

### Softening point

Figure 4 shows that there was considerable overlapping of values of softening point for the asphalts of the 60–70, 85–100, and 120–150 grades but there was a definite difference in the point at which the peak occurred for each grade. The values of the medians were 125°, 117°, and 110° F. for the three grades. Data selected from table 5 and plotted in figure 5 illustrate the relation between softening point and penetration for different grades from the same refinery. It will be noted that the differences between values for different grades from the same source are essentially the same as the differences in the median values for all asphalts in each grade.

### Furol viscosity at 275° F.

There was considerable overlapping of values for the Furol viscosity of the three penetration grades, as shown in figure 6. However, there was a distinct difference in the median values for the three grades—being 277 seconds, 200 seconds, and 146 seconds for the 60–70, 85–100, and 120–150 grades. The ranges in viscosity values for the three penetration grades were 144 to 431, 85 to 318, and 71 to 250 seconds, respectively.

The relation of penetration at 77° F. to Furol viscosity at 275° F. for asphalts of the different penetration grades from the same sources are illustrated in figure 7. The upper and lower lines represent the extreme viscosities for the asphalts. The upper line shows the penetration-viscosity relation for the three grades of asphalt refined from a Mexican crude by refinery 22. The asphalts from refinery 23 had the lowest viscosity for equivalent penetration of those represented by three or more grades given in table 5 but there were a few asphalts from other sources that had lower viscosities. The two asphalts refined from a California crude by refinery 66 had the lowest Furol viscosity for equivalent penetration for all the materials tested and therefore they were used to establish the lower viscosity line. Other penetration-viscosity relations shown are believed generally typical of materials from other sources.

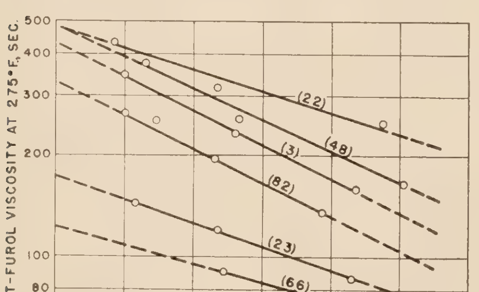


*Figure 7.—Relation of penetration at 77° F. to Furol viscosity at 275° F.*

The data selected for presentation in figure 7 generally fall into a straight line, but it should be noted that some of the asphalts of different grades from the same refinery did not show this straight-line relation. It was also not possible to determine from the data the extent to which the linear relation would be applicable to softer or harder materials than those tested. However, the data serve to show the wide difference in the high temperature viscosities of asphalts of the same grade. The significance of these differences are discussed later.

### Penetration ratio

Values for the ratio of the penetration at 39.2° F., 200 g., 60 sec., to the penetration at 77° F., 100 g., 5 sec., as shown in figure 8, did not vary significantly for the 85–100 and 120–150 grades. The minimum and maximum values and the relative position of the distribution curve for the 60–70 asphalts indicated slightly higher penetration ratios than for the 85–100 and 120–150 asphalts.

Figure 9 illustrates the relation of the penetration at 77° F. to the penetration ratio for asphalts of different grades from the same refinery source. Some series of asphalts from the same source showed little change in penetration ratio for different grades. Others showed a decrease in penetration ratio with increase in penetration, while still other results were quite erratic and no uniform trend could be determined. In some cases this could have been attributed to the greater amount of blowing to reduce the lower penetration materials to grade.

A relation between the Furol viscosity at 275° F. and the penetration ratio might be expected since both values are assumed to be dependent on the viscosity-temperature relationship of the asphalt. However, when asphalts of different grades and sources were compared, no definite trend was established. This could have been attributable to differences in the plastic flow properties of various materials, or possibly due to the empirical nature of the penetration ratio.

### Ductility at 77° F., 5 cm. per minute

Because of the influence of consistency, it is difficult to evaluate trends in the ductility results for asphalts from different penetration grades. Figure 10 shows that 38 percent of the 60–70 asphalts and 6 percent of the 85–100 samples had ductility values greater than 250 cm., the capacity of the ductility machine. All of the 120–150 grade materials had values less than 250 cm. Even though more 60–70 asphalts exceeded 250 cm. than the other grades, there were also a greater number of samples of this grade that had ductility values less than 100 cm., the minimum requirement most commonly found in specifications.

### Ductility at 39.2° F.

The frequency distribution for the ductility at 39.2° F., 1 cm. per minute is shown in figure 11. While there was similarity in the polygons for the 60–70 and 85–100 grades, the polygon for the 120–150 grade was radically different. The ductility ranges were 2.8 to 24.0 cm. for the 60–70 grade, 3.5

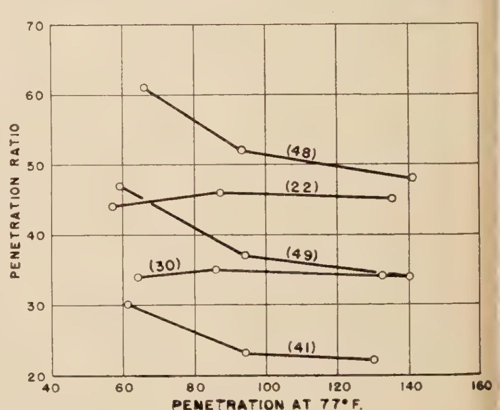


*Figure 9.—Relation of penetration at 77° F. to penetration ratio.*

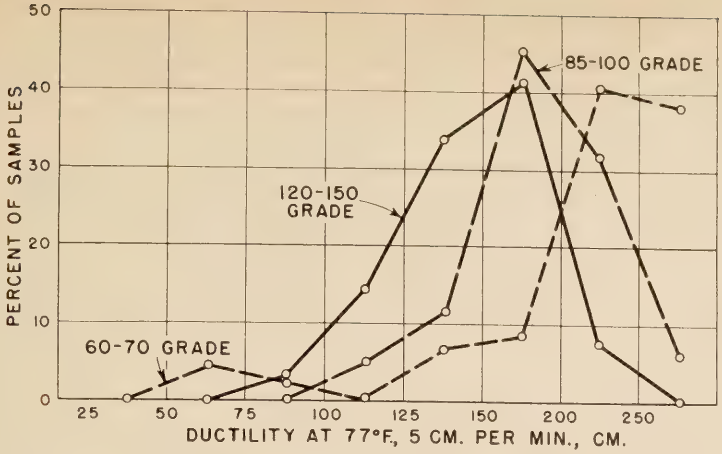


*Figure 10.—Distribution of ductility.*

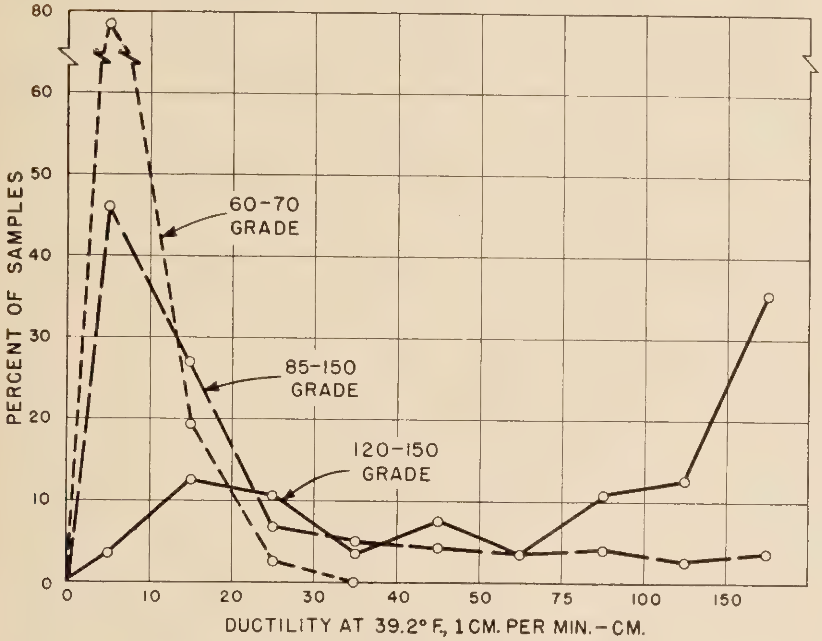


*Figure 11.—Distribution of ductility at 39.2° F.*

to 250+ cm. for 85–100 grade, and 6.3 to 250+ cm. for the 120–150 grade. The percentage of samples that had ductilities less than 10 cm. were 69 for the 60–70, 47 for the 85–100, and 4 for the 120–150 asphalts.

While it has been established that the ductilities of asphalts from different sources and methods of refining vary greatly, it also has been established that consistency as measured by penetration has a pronounced effect on ductility values at low temperatures. The influence of penetration on ductility at 39.2° F. and variability in ductility of asphalts from different sources is illustrated in figure 12. The wide difference in the ductilities of asphalts from various sources when compared on an equipenetration basis as well as the large decrease in ductility with decrease in penetration for materials from the same source are shown.

### Flash points

Figures 13 and 14 respectively, show the distribution of flash points determined by the Pensky-Martens closed cup and the Cleveland open cup apparatus. Very little difference was apparent between the results of flash points of the 85–100 and 120–150 grades, but the shift toward higher values for the 60–70 grade was appreciable. The relation between the results for the closed cup and open cup apparatus showed the same erratic pattern for the 60–70 and 120–150 grades as was noted for the 85–100 penetration asphalts. Also, there were no consistent trends indicated from the data in table 5 for asphalts of different grades from the same source. In a few samples there was a decrease in flash point with increase in penetration but in other samples this result was not evident.

### Thin-film oven test, loss in weight

The change in weight during the heating of the asphalts in the ⅛-inch film for 5 hours at 325° F. is shown in figure 15. The positive values on the horizontal axis indicate a gain in weight and the negative values indicate a loss. Eighty-five percent of the 60–70 asphalts, 65 percent of the 85–100, and 66 percent of the 120–150 grade materials had slight gains or losses in weight less than 0.20 percent. Although not shown, the median values for the three grades were approximately the same. The most significant fact shown is that there were some asphalts of all three grades that had relatively high loss in weight.

Two percent of the 60–70 grade samples, 13 percent of the 85–100 grade samples, and 21 percent of the 120–150 grade samples had losses greater than 0.50 percent. However, where series of asphalts of different penetration grades from the various sources were compared the trend for higher losses in higher penetration asphalts was not consistent. This is evident in figure 16 where the change in weight is plotted against penetration for the different grades from the same source. It is of interest to note the two distinctive patterns of behavior. Generally, the materials that had significant losses showed a very definite trend toward higher loss for the increasing penetration, the relation being essentially linear. However, where a refinery produced asphalts with very little losses or with gains in weights, variation with grade was erratic and of little significance. The major exception to this trend was found in the analysis of the asphalts from refinery 48. The 60–70 grade asphalt from this refinery had a fairly high loss and the loss increased only slightly for the 85–100 and 120–150 penetration grades.

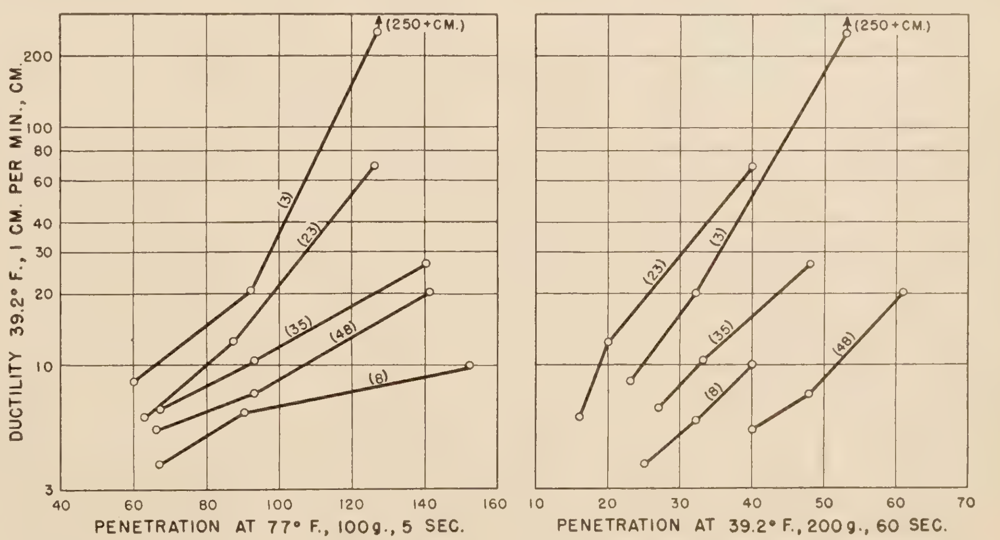


*Figure 12.—Relation of penetration at 77° F. and 39.2° F. to ductility at 39.2° F.*


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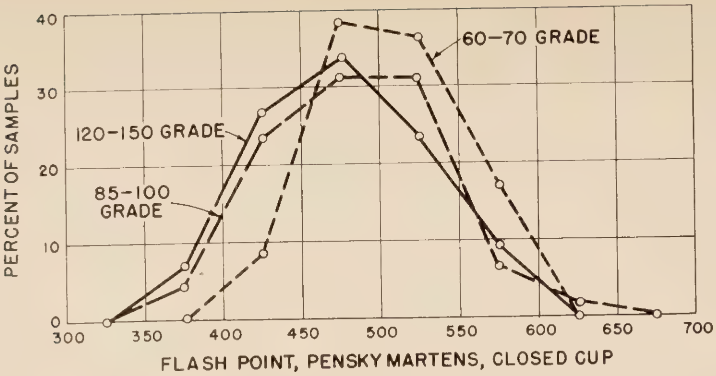


*Figure 13.—Distribution of flash points (closed cup).*

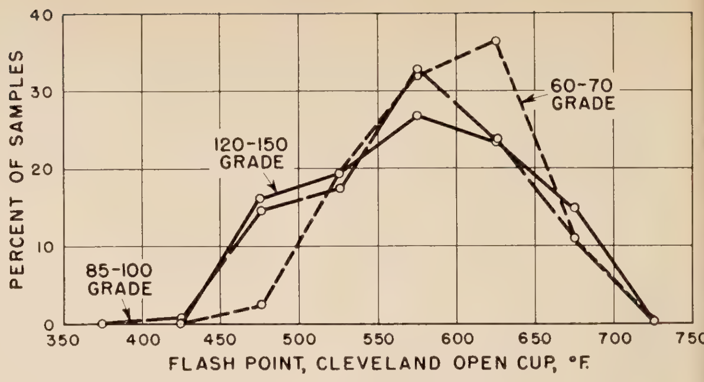


*Figure 14.—Distribution of flash points (open cup).*

**Retained penetration, thin-film oven test**

In conjunction with the comparisons of loss in weight in the thin-film tests, there also was a significant difference in the percentage of the original penetration retained by the residues from the thin-film oven test for the 60–70, 85–100, and 120–150 penetration grades of asphalt. In general, the higher the penetration of the original asphalts the lower the percentage of retained penetration. The frequency distribution graph for the three grades is shown in figure 17. All of the 60–70 penetration asphalts retained more than 55 percent, while 10 percent of the 85–100, and 25 percent of the 120–150 penetration asphalts retained less than 55 percent. The median value for retained penetration was 66 percent for the 60–70 grade, 61 percent for the 85–100 grade and 58 percent for the 120–150 grade.

The effect of the original consistency on retained penetration is illustrated further in figure 18 for some of the asphalts of various grades from the same sources given in table 5. This graph shows that although there was a wide range in retained penetration for asphalts within each grade, there also was a fairly uniform decrease in retained penetration as the original penetration increased. These conclusions support the decision of the various specification writers to establish limits for percentage of retained penetration on a sliding scale for different penetration grades.

**Softening point of thin-film residues**

The softening points of the residues from the thin-film oven tests, figure 19, show considerable overlapping of the values. The overall range of the softening point of the residues for the three grades of asphalt was 111° F. to 147° F. The range for the 60–70 grade was 126° F. to 147° F., for the 85–100 grade 118° F. to 140° F., and for the 120–150 grade 111° F. to 133° F. The increase in the softening point for individual samples during the test varied considerably. Increases for the 60–70 grade varied from a minimum of 3° F. to a maximum of 17° F. For the 85–100 penetration asphalts individual increases varied from 5° F. to 17° F. The 120–150 grade showed increases varying from 3° F. to 22° F. The median increase for all grades was in the range from 8 to 10 degrees.

**Ductility of thin-film residues**

The distribution of the ductility of the thin-film residues for the 60–70, 85–100, and 120–150 penetration asphalts is shown in figure 20. Initially 3 of the 60–70 asphalts and 2 of the 120–150 asphalts had ductility values of less than 100 cm. There were no ductility values of less than 100 cm. for the 85–100 penetration asphalts. After the thin-film test the percentages of asphalts of each grade that had ductility values less than 100 cm. were approximately 23, 18, and 7, respectively, and 15, 7, and 0 percent of the residues had ductility values less than 50 cm.

It is of interest to note that the ductilities of many of the thin-film residues were higher than the original asphalt. Nineteen percent of the 60–70 asphalts, 42 percent of the 85–100 asphalts, and 71 percent of the 120–150 asphalts increased in ductility during heating in the thin-film test. This was accounted for by the hardening during heating that put these asphalts within the range of consistency for higher ductility.

**Standard oven-loss tests**

Plotted data for the standard loss tests have not been included since there was little significance to the results obtained. All of the 60–70 penetration materials had losses of less than 0.20 percent, while 97 percent of the 85–100 materials, and 89 percent of the 120–150 materials had losses of less than 0.20 percent. Maximum loss values for the 60–70, 85–100, and 120–150 grades were 0.18, 0.58, and 0.27 percent, respectively. The minimum percentages of retained penetration for the oven-loss residues for the above grades were 78, 75, and 77, respectively.

The low values for loss and the high values for retained penetration in the standard oven-loss test for all grades of asphalts covered by this report further confirms the inadequacy of the test for evaluating the hardening characteristics of asphalt cements.

**Oliensis spot test**

Oliensis spot tests using standard naptha were made on all of the 60–70 and 120–150 penetration grade asphalts. (Results of the spot tests on the 85–100 penetration grade asphalts were reported in part I.) Only 3 asphalts of the 60–70 and 120–150 asphalts were found to have a positive reaction. These were samples Nos. 154 (60–70 grade) and 226 (120–150 grade) from refinery 23. Sample No. 69, the 85–100 grade asphalt from the same refinery, also showed a positive spot. Asphalts from this source refined from a West Texas crude, have been known to produce positive spots even when vacuum or steam

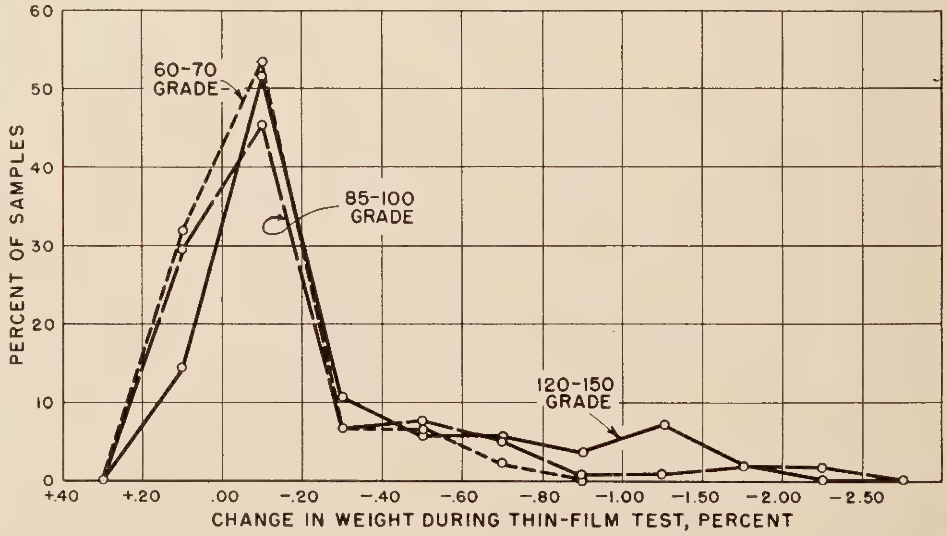


*Figure 15.—Distribution of change in weight during thin-film test.*

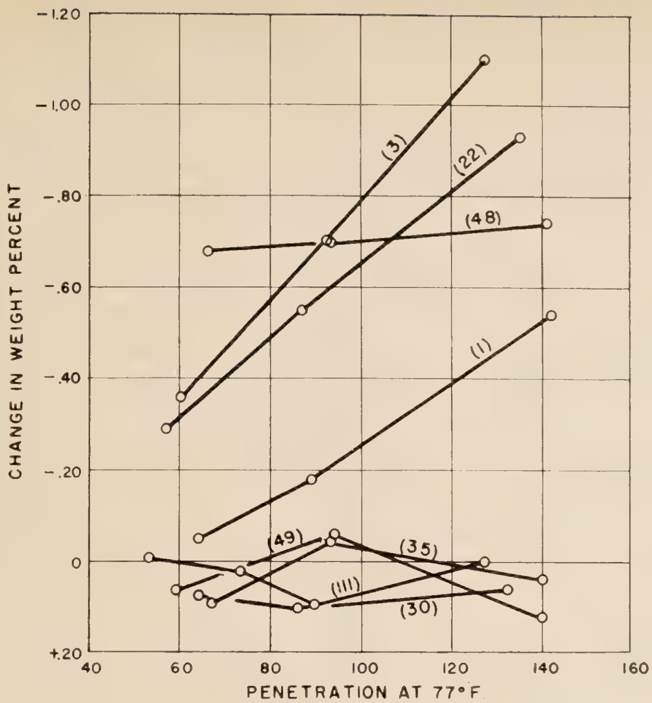


*Figure 16.—Relation of penetration at 77° F. to change in weight in thin-film oven test.*

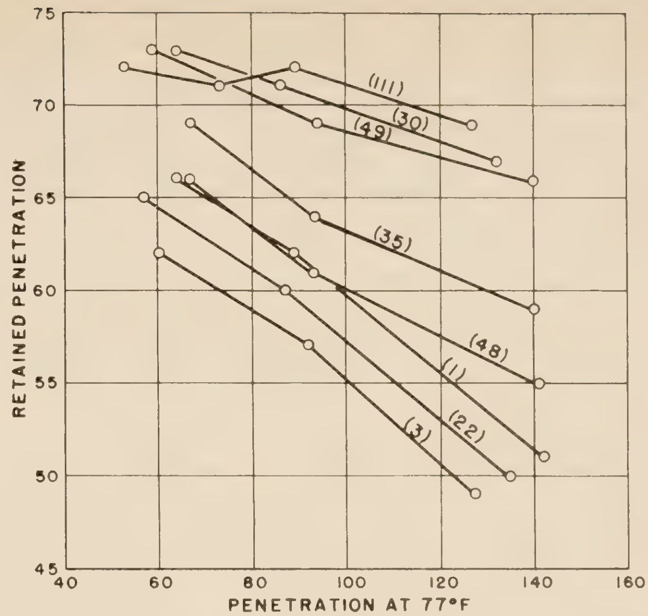


*Figure 18.—Relation of penetration at 77° F. to retained penetration of thin-film residues.*

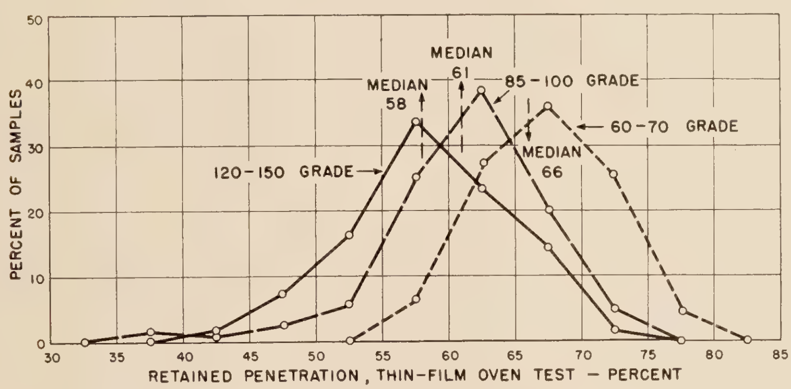


*Figure 17.—Distribution of retained penetration of thin-film residues.*

distillation are used. Sample No. 218 (120–150 grade) from refinery 38 also showed a positive reaction as did sample No. 98 in the 85–100 grade from the same source. No 60–70 asphalt was received from this producer.

Thus the results of spot tests on all grades of asphalts reported here and in part I indicate that very few of the present day asphalts would fail such requirements in specifications, particularly if small amounts of xylene are used with the standard naptha as is generally specified.

## General Discussion of Data

The test results reported here and in part I were obtained primarily to provide current information on the properties of asphalt cements used in highways in the United States. The groups of samples in the 60–70, 85–100, and 120–150 grades were believed to represent nearly all asphalts of these grades produced and used at the time of sampling. While there may have been some changes in crude sources or methods of refining since 1955 when the samples were collected, the results of tests are believed to be indicative of the properties of asphalts produced today.

It was pointed out in part I that 12 of the 119 samples of the 85–100 penetration grade asphalts, or about 10 percent, failed to meet the standard specifications employed by the majority of the States. The test data for the other grades reported here show that 13 samples, or about 28 percent, of the 60–70 grade, and 4 samples, about 7 percent, of the 120–150 grade also were outside the required penetration limits. However, while this appears to be a rather high number of samples outside specifications, it should be noted that of the 29 samples of all grades that failed to meet the penetration range, 21 of these were within the current precision requirement for reproducibility of the penetration test.

Other than the penetration test, only 3 of the 85–100 grade asphalts failed to meet any standard AASHO specification requirement. There also were 3 samples of the 60–70 asphalts and 2 of the 120–150 asphalts that had ductility values less than 100 cm., and a single 120–150 asphalt that did not meet the requirement for solubility in carbon tetrachloride.

It was brought out in the first report that many of the current specifications, such as those of the AASHO, fail to measure the relative quality of asphalt and that asphalt materials meeting these specifications may actually show poor performance in service. Consequently during the past four years, a number of agencies have revised their asphalt specifications in an effort to raise the overall quality of asphalt. Several of the Western States followed California's lead and adopted specification requirements based on the Pensky-Martens closed cup flash test, the penetration ratio, the Furol viscosity at 275° F., and the thin-film oven test. The requirements adopted for these specifications were cooperatively developed by conferences of western producers and consumers and undoubtedly have been of value in eliminating some poor materials and in upgrading others. However, tests made by the Bureau of Public Roads show that the western requirements for the Pensky-Martens flash point, the penetration ratio and the Furol viscosity at 275° F. would not be applicable on a national basis.

Flash point requirements in specifications are intended to indicate the temperature at which asphalts may be safely heated. It was found that the presence of silicones in asphalts, which had been added during refining or storage to reduce foaming tendencies, often caused erroneous flash points by the Cleveland open cup method. The Pensky-Martens closed cup method was adopted by some of the Western States to avoid this error. The States set minimum specification limits for the 60–70, 85–100, and 120–150 penetration grades at 450° F., 440° F., and 425° F., respectively. The percentage of asphalts in the above grades that failed to meet the requirements were 9, 22, and 18.

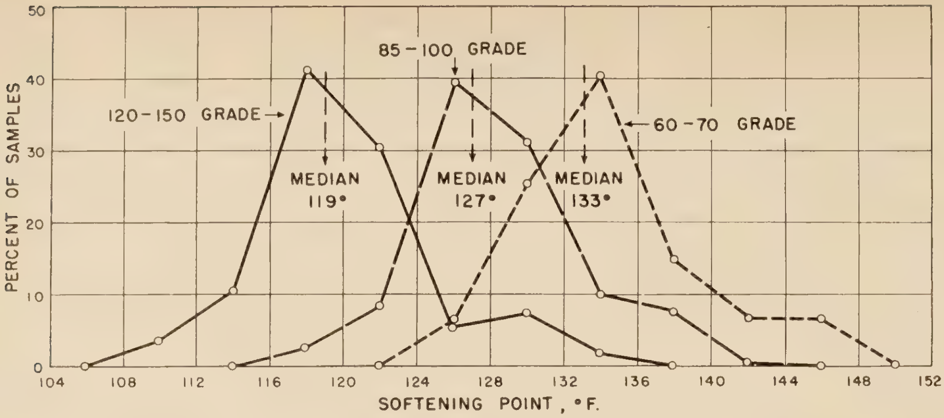


*Figure 19.—Distribution of softening point of thin-film residues.*

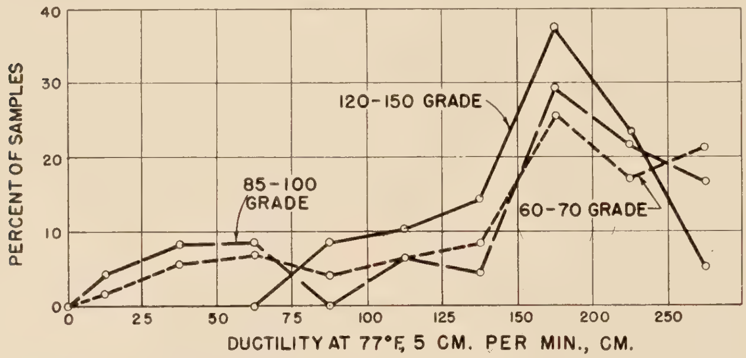


*Figure 20.—Distribution of ductility of thin-film residues.*

While the Pensky-Martens closed cup test may serve a useful purpose in obtaining truer flash points where silicones are present in the asphalt, the specification limits should not be set so as to exclude asphalts having good service records. Since many of the asphalts that failed the western requirements apparently were of good quality, those limits should not be adopted on a nationwide basis.

The ratio of the penetration at 39.2° F., 200 g., 5 sec., to the penetration at 77° F. 100 g., 5 sec., may serve a useful purpose in restricting the use of highly temperature-susceptible asphalts. However, the minimum requirement of 25 adopted by the Western States would have little significance if applied on a national basis. A discussion of the penetration ratios of the 85–100 asphalts in part I of the study pointed out that there was a general trend for the asphalts from the eastern sources to have the highest penetration ratios and those from western sources the lowest. The asphalts from the central areas had intermediate values. Similar trends were found for the other grades reported here. The variability in penetration ratios of asphalts throughout the country again stresses the need for the extreme caution that must be used to establish significant specification requirements.

Penetration ratios employing differences in time of penetration and loading, such as that used in the western specifications, are not believed to be true indexes of susceptibility because of the combination of test variables other than temperature. In the report on the properties of asphalts produced in the midthirties it was shown that the slope of the log-penetration temperature curve represented a useful measure of susceptibility that was more nearly related to the rheological properties of the material than any of the empirical ratios (1).[3] It is believed that if a temperature-susceptibility index is a needed requirement in asphalt specifications, consideration should be given to the use of the slope of the penetration curve or values based on fundamental measurements of consistency.

Another feature of the quality specification that serves to limit the viscosity temperature relation is the furol viscosity at 275° F. This requirement is, in effect, also a control of the temperature susceptibility of asphalt. The western specifications have established limits of 100 to 325, 85 to 260, and 70 to 210 seconds, respectively, for the 60–70, 85–100, and 120–150 grade asphalts. All of the penetration asphalts exceeded the lower limits of these requirements, but there were a number of asphalts of each grade that had viscosities higher than the maximum requirement. Approximately 30 percent of the 60–70, 8 percent of the 85–100, and 7 percent of the 120–150 asphalts had viscosities above the upper limits. Many of these asphalts are used extensively in the Eastern States and are considered to be satisfactory materials. It is again evident that if high-temperature viscosity requirements are desirable for adoption in specifications on a nationwide basis a further study should be made to establish proper limits.

To date no detailed study of the viscosity-temperature characteristics of the asphalts of this study has been made. The wide range in the viscosities values at 275° F. of the asphalts in each grade shows the necessity for giving more consideration to establishing temperatures for plant mixing and spray applications on the basis of viscosity. The difference in viscosity of the asphalts at this high temperature also indicates that there may be considerable variation in the viscosities in the temperature range to which the asphalt is subjected in the pavement. Such variations may be significant from the standpoint of the essential engineering properties.

During the past year the thin-film oven test, which was developed by the Bureau of Public Roads, received greater recognition when it was adopted by the Asphalt Institute as a specification test. The AASHO (American Association of State Highway Officials) Committee on Materials also approved the test and asphalt cement specifications have been adopted which include the thin-film oven test with suggested limits. While the Asphalt Institute specifications include requirements for retained penetration only, the AASHO specifications include the additional requirements for a maximum loss in weight and a minimum ductility of the residue. The test limits are similar to those currently in effect in a number of State specifications. Table 6 gives a summary of the test limits used by the AASHO, the Asphalt Institute and the Western States.

The limits for retained penetration suggested by the AASHO and those used by the Asphalt Institute are shown graphically in figure 21 together with the results and an analyses of the test data on the 3 penetration grades of asphalts.

The Asphalt Institute requirements for retained penetration are slightly lower than those in the AASHO specification for the lower penetration grades and this difference decreases as the penetration grade increases. In order to compare these specification limits with the results of the retained penetration of the asphalts reported in this study, two sets of

[3] Italic numbers in parentheses refer to the list of references on p. 99.

**Table 6.—Specification requirements for the thin-film oven test**

| Penetration grade | Loss in weight not more than— | | Retained penetration at 77° F. not less than— | | | Ductility of residue at 77° F., not less than— | |
|---|---|---|---|---|---|---|---|
| | AASHO [1] | Western States [2] | AASHO | Western States | Asphalt Institute | AASHO | Western States |
| | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Cm.* | *Cm.* |
| 40–50 | 0.8 | 0.75 | 55 | 52 | 52 | -------- | 50 |
| 60–70 | .8 | .8 | 52 | 50 | 50 | 50 | 50 |
| 85–100 | 1.0 | .85 | 47 | 47 | 45 | 75 | 75 |
| 120–150 | 1.3 | 1.0 | 42 | 44 | 42 | 100 | 75 |
| 200–300 | 1.5 | 1.5 | 37 | 40 | 37 | 100 | 75 |

[1] Limits suggested for AASHO specification M 20–59. [2] Limits used by Western States.

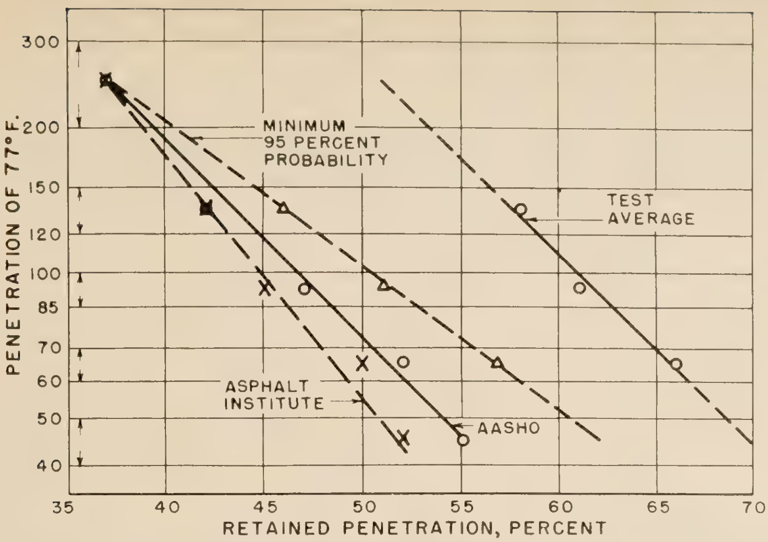


***Figure 21.—Specification requirements for retained penetration, thin-film oven test.***

values are also shown in figure 21. These are the average values for the 60–70, 85–100, and 120–150 grades and the minimum values established for 95 percent probability (the average − 1.96 × standard deviation), for the same grades. Although there is no particular significance to be attached to the 95 percent probability limits with respect to asphalt quality, the values are used here as a gage of the applicability of the specification limits that are proposed or in use. The Asphalt Institute limits are approximately parallel to the line shown for the average values and are about 15 percentage-points lower. The AASHO limits are nearer those established by the 95 percent probability line but are still 7 percentage-points lower in retained penetration for the 40–50 grade asphalts and the differences decrease for the higher penetration grades.

It should be emphasized that the asphalts, with possibly a few exceptions, were not produced to meet the requirements for the thin-film test. Even with this consideration there were very few asphalts that would be penalized by the AASHO limits for retained penetration which allows for differences in the reproducibility of the test. None of the 60–70 asphalts failed the requirement for retained penetration of 52 percent. Four of the 85–100 penetration asphalts were less than 47 percent, and none of the 120–150 asphalts were less than 42 percent.

The data indicate that there was no exact correlation between the amount of loss and the hardening, but where the loss was appreciable it affected hardening to a considerable degree. The relation between loss and hardening also gave some indication as to the type of hardening that occurred. Therefore, loss values are considered significant and should be determined.

All of the 60–70 asphalts had losses less than 0.8 percent, the maximum requirement suggested by the AASHO. Five of the 85–100 asphalts failed the requirement of 1.0 percent and 3 of these also failed to meet the minimum requirement for retained penetration. One sample of the 120–150 asphalts did not pass the requirement of 1.3 percent. This asphalt had a retained penetration of 42 percent, the minimum requirement of that grade.

Even though the amount of change in the ductility during the thin-film tests may not be indicative of quality, it is believed that the actual ductility of the residue is significant. Data obtained show that some asphalts retained a high percentage of penetration and yet became relatively nonductile.

The minimum requirements for ductility of the residues from the thin-film test suggested by the AASHO specification for the 60–70, 85–100, and 120–150 grades are 50, 75, and 100 cm. respectively. A minimum ductility of 100 cm. was also specified for the 200–300 grade asphalts. No requirement was specified for the 40–50 grade asphalts. Of the asphalts that did not meet the minimum ductility requirements, 6 were samples in the 60–70 grade, 17 were in the 85–100 grade, and 4 were in the 120–150 penetration grade. These are equivalent to 13, 14, and 7 percent of the asphalts included in each grade.

The most suitable limits for ductility requirements on the thin-film residues are debatable. It was pointed out in the report on the 85–100 asphalts that a minimum limit of 75 cm. appeared to be suitable for the Western States but that this requirement might be somewhat severe for the asphalts produced in the midcontinent area. The minimum requirement of 50 cm. for the 60–70 asphalts also might be somewhat severe for the asphalts produced in the midcontinent area. However, the minimum requirement of 100 cm. for the 120–150 grade appears to be satisfactory.

### *Summary*

It is believed that the greatest value of these studies are the test results themselves. While the data reported include primarily the results of the tests used in current specifications, they serve to establish the range and medians for test values that may be expected on a national basis. Thus, they provide background information that may be used as a guide for evaluating the older specifications for asphalt cements and for judging the applicability of new tests and requirements.

It is recognized that the data offer many possibilities for analyses other than those presented here and in part I. It is believed that various trends and interrelations of the data will be of varying degrees of interest to producers, engineers, and researchers and that each may want to analyze the data in a different manner to obtain the desired information.

The analysis and discussion of the test results have served to show the inadequacy of many of the current specification requirements for asphalt cements and to illustrate the wide differences that exist in asphalts meeting the same specifications.

The need for additional studies to evaluate the significance of the differences in asphalts should be emphasized. The differences in the temperature susceptibility of asphalts have received recognition by some agencies to control plant mixing temperatures on an equi-viscosity basis. Some consideration is also being given to the effect of the differences in viscosity of asphalts on the compaction of paving mixtures on the road. However, the full significance of these differences needs to be established. The wide range in viscosities at the high temperatures raises a question as to amount of variation in viscosities of asphalts in the temperature range they are subjected to in the pavement. Research also is needed to evaluate the significance of these differences.

More information is needed concerning the hardening characteristics of asphalts. It is generally recognized that hardening during the fabrication of pavements should be limited and that this can be done effectively by the proper use of specification requirements for the thin-film oven test together with proper temperature control during plant mixing. However, studies are needed to evaluate the hardening of asphalts in pavements at road temperatures and the effect of the many variables on the hardening, such as mixture composition, design, and density of pavement.

There are some areas of research that are not a part of these studies that should be kept in mind in relation to the improvement of quality of asphalts and the development of better tests and specifications. For example, there is some concern among the States with the variability of the wetting and adhesion characteristics of asphalts. There have been some reports that modifications made to reduce hardening tendencies have resulted in poorer adhesion. This factor needs to be studied.

Asphalt technology is still based primarily on empirical tests and relations developed by trial and error methods and these will undoubtedly be continued in use for a long time. Nevertheless, the interest in developing truly fundamental data and information on rheological properties is increasing rapidly and new tools such as the Zeitfuchs capillary viscometer and the sliding plate microviscometer have been developed to make the task

(*Continued on page 99*)


562153—60——3

# Trans-Hudson River Vehicular Origin and Destination Survey

*By The Port of New York Authority*
*Port Development Department*
*Planning Division*

**Reported by WARREN LOVEJOY,[1] Transportation Economist**

*A new origin and destination survey technique, called "continuous sampling," is described in this article. The big gain in this technique is the better quality of results obtained by interviewing, spread over a whole year, with approximately the same number of interviews that would be conducted in a "one-shot" survey concentrated in a small period of time. The continuous sampling technique, based on probability samples, spreads the interviewing over a long period of time and thus obtains a full variety of daily, weekly, and seasonal traffic patterns. The method is efficient and economical since it enables a small number of experienced interviewers to do all the interviewing and coding, and avoids intensive activity at any facility at any one time. In addition, the technique permits periodic analyses and provides up-to-date information, since the data are continuously obtained, and makes possible calculation of measures of sampling variability. All of these features of the continuous sampling technique tend to result in better representation of changing traffic patterns.*

*By using the continuous sampling technique, the Port of New York Authority, which devised the procedure, obtained statistically reliable information as to the origins and destinations of automobiles and trucks using the three major Hudson River crossings between New York City and New Jersey—the George Washington Bridge and the Holland and Lincoln Tunnels.*

*In 1958, a total of 80.7 million motor vehicles used the three crossings—an average daily traffic of 221,000 vehicles. Ninety-seven percent of these vehicles had at least one terminus in the 18-county New York-New Jersey metropolitan area. The largest share of weekday traffic, 34 percent, either originated in or was destined to the Manhattan central business district.*

*Classified by trip purposes for the year, 47 percent of the automobiles crossed the trans-Hudson facilities for work, 51 percent for recreation and personal reasons, and only 2 percent for shopping purposes. Classified according to the day of the week, automobile trips for business purposes accounted for 63 percent of the weekday trips, 24 percent of the Saturday trips, and 11 percent of the Sunday trips. Recreation and personal trips increased from 35 percent on weekdays to 73 percent on Saturdays and 88 percent on Sundays. Seasonally, the proportion of weekday business trips by automobiles varied from 57 percent in the summer to 68 percent during the winter.*

*On an hourly basis, during the 7–10 a.m. period 87 percent of the eastbound and 86 percent of the westbound weekday automobile trips were for work purposes. In the 4–7 p.m. period, however, only 68 percent of the eastbound trips and 72 percent of the westbound trips were for business purposes.*

*Traffic patterns of 1958 compared with those of 1949 are also reported in this article. The comparisons showed that traffic originating and terminating in each of the counties in the metropolitan area increased substantially over the 9-year period, with the greater percentage increases being most pronounced in the outlying counties. This and other indications appear to emphasize the growing importance of peripheral facilities and routings.*

*Changes in truck traffic patterns from 1949 to 1958 were less pronounced than those shown for all vehicle trips combined. Truck traffic increased only 23 percent over the 9-year period, whereas total trans-Hudson traffic increased 59 percent over the same period.*

## THE SURVEY TECHNIQUE

REASONABLY ACCURATE and up-to-date origin and destination information is one of the primary tools used in the planning of vehicular facilities. Since 1930, the Port of New York Authority, in connection with its planning for future vehicular facilities across the Hudson River in the metropolitan New York-New Jersey area, has conducted periodic roadside interview surveys of origins and destinations of vehicles using its tunnels and bridges. Included in the surveys were the Port Authority's vehicular facilities that connect New York City with the mainland to the west: the Holland and Lincoln Tunnels and the George Washington Bridge, the three vital Hudson River crossings between the island of Manhattan and New Jersey; and the Outerbridge, Goethals, and Bayonne Bridges, which connect Staten Island with New Jersey.

In the past, so-called "one-shot" surveys have been employed in which the traffic of 1 to 3 days has been surveyed as representative of the entire year's traffic. These surveys were made approximately at 3-year intervals. While these short-term surveys provided a substantial body of origin-destination information over the years, it was felt that improved methods of obtaining the desired information were possible. A study was consequently undertaken, which resulted in the adoption in January 1958 of a new sampling technique called "continuous sampling."

Briefly, this technique is based on a carefully designed and controlled probability sample which builds up the interviews obtained to the required number for any desired degree of reliability by sampling over a considerable length of time rather than by sampling heavily in a short period of several days. Thus, in the continuous survey, by obtaining a few hundred interviews each day, a substantial number of interviews were accumulated over the course of the year 1958. These were obtained under all of the varying conditions that existed in the field throughout the year. Some of the resulting 1958 data for the three Hudson River crossings are presented later in this article. The Port Authority has continued the sampling survey throughout 1959 and in 1960.

### Advantages of continuous sampling

There are a number of advantages to be derived from the use of the new traffic survey technique. Among the more important of these, as they apply to the Port Authority's origin and destination survey problem, are the following:

1. By spreading the sampling over a long period of time, this system avoids the possibility inherent in "one-shot" surveys that seasonal or other variations might make traffic on the day or days surveyed unrepre-

[1] Paul Rackow, Economic Analyst with the Port of New York Authority, was responsible for much of the work in this survey.

ntative. In continuous sampling, a sufficient ariety of traffic patterns are covered through-it the year so that the survey results are presentative of normal traffic patterns.

2. Up-to-date information on origin and stination patterns is provided at any time ecause the survey data are continuously eing obtained and can be analyzed periodi-lly, as necessary.

3. Building the size of the sample over a ng period, rather than by intensive sampling aring just a few days, has eliminated the ecessity of hiring large numbers of unskilled, mporary employees as interviewers and oders. For the continuous sampling, four gularly employed interviewers did all of e interviewing as well as the coding. These en were well trained in interviewing meth-ls, had a thorough knowledge of the geog-phy of the metropolitan area, and were illed in the coding of the data.

4. Since continuous sampling avoids inten-ve activity at any facility at any one time, ere was less chance of causing traffic con-estion while obtaining the origin and destina-on information. Furthermore, skilled inter-ewers greatly reduced the time required r each interview and were thus able to get mplete information on each interview ithout undue delay to the motorist.

5. By using a probability sample, it is ossible to compute mathematically the egree of reliability achieved by the survey ad thus keep a constant check of the accuracy the results.

### ata obtained

During 1958, a total of 92,329 interviews ere obtained at six river crossings. This umber of interviews represented 0.1 percent the 85.7 million automobile and truck trips 1958 actually recorded at these crossings. hile the proportion of sampling may appear be remarkably small, the results were und to be statistically reliable.

An interview response rate of nearly 99 per-nt was achieved and in all cases the full nount of information covered by the inter-ew form was obtained. This exceptionally gh rate of response represented a con-derable improvement over the level achieved the "one-shot" surveys conducted in the ast, thus ensuring a high degree of reliability this phase of the survey results.

While the basic purpose of the survey was obtain information as to the origins and stinations of automobiles and trucks using e Port Authority bridges and tunnels, pplementary information was obtained con-rning purpose of trip, State in which the hicle was registered, number of passengers, pe of vehicle, and time, day, and direction trip. Buses were not included in the sur-y, because information on bus routes was ailable from other sources.

## *Survey Design*

The sample design for the 1958 survey had be both economical and practical in order meet the necessary restrictions as to reason-ble work loads and the various working conditions which would be encountered in the field. The experience of the first year of operation (1958) and analysis of the survey results have indicated that the sample design did, in fact, meet these requirements.

There were a number of specific require-ments which the survey had to be designed to accomplish:

1. Sample estimates had to be produced for a great variety of specified lines of travel with many different levels of traffic volume. A line of travel was defined as traffic moving between two geographically specified zones. These estimates had to be provided not only for the Port Authority vehicular crossings combined, but for each facility separately, on an annual basis as well as for each of the four seasons of the year.

2. The statistical population from which the sample was to be taken included all revenue (toll-paying) automobiles, trucks, and tractor-trailers using the Port Authority vehicular crossings on weekdays, Saturdays, and Sun-days.

3. The sample was to be a probability sample requiring that every vehicle trip made during the year have a known probability of selection. This was to be achieved by a randomized-selection procedure at every stage of the sample design.

4. The level of reliability required in the survey specified that with the expected overall sample size of 100,000 interviews, a sample estimate of 1 percent, or 1,000 interviews, would have a coefficient of variation (maxi-mum margin of error) of the order of 3 to 6 percent.

5. There had to be built into the sample design a procedure for developing proper measurements of the standard errors of the various sample estimates.

### Development of general sample design

The general sample design had to be such that all of the statistical requirements for a probability sample were met. The design also had to accommodate the practical prob-lems encountered in the actual conduct of the survey. These two considerations necessi-tated development of a number of procedures, which are outlined in the following paragraphs.

The survey budget permitted the assign-ment of four permanent field survey inter-viewers to this project. These interviewers were to be responsible for both the field work and the office work in connection with the survey. Since this was the limit of the man-power available, it was determined that the field work had to be restricted to 11 tours of duty per week.

Reasonable working hours and the necessity of minimizing fluctuations in hourly traffic volumes within shifts were used as the criteria in designating the hours for shifts, which became the primary sampling units. The shifts were set up as 8-hour periods to be spent at one facility on any one of the seven days of the week. The hours of the shifts decided upon were 11 p.m.–7 a.m., 7 a.m.–3 p.m., and 3 p.m.–11 p.m.

To insure good coverage of origin and destination patterns, directional flows, vehicle types, and traffic volumes at each facility during each 8-hour period, the design provided that the interviewer would move from one lane to another each hour in a prescribed pattern of rotation. Specified relief periods were included in each hour, but it was assumed, with good reason, that the traffic patterns during these relief periods would not be different from those sampled during the interviewing periods.

Because of the distances involved in cover-ing the entire toll plaza of a facility, which ranged from 14 to 26 lanes, and were in some cases geographically separated, it was neces-sary to subdivide each facility into two or more "locations." These locations were selected in such a manner as to allow an interviewer to enumerate the number of lanes open within a location in each hour. The interviewer would rotate among the lanes at one specified loca-tion for 4 hours and then move on to another location.

Experience with previous "one-shot" sur-veys, supplemented by field testing, indicated that an average work load of 40 interviews per hour could be achieved by an interviewer. This does not mean that in very busy periods more than 40 interviews per hour could not be obtained. It does mean that throughout the conduct of the survey an average rate of about 40 interviews per hour was achievable.

A knowledge of hourly traffic variations at each facility on the different days of the week was utilized in selecting uniform sampling rates during each shift that would allow for reasonable work loads for the interviewers. The possibility of selecting any shift at any facility was proportionate to the amount of traffic volume expected to occur during that shift.

To assure a self-weighting sample, a pro-cedure of balancing actual interviews against expected interviews was introduced. Thus, interviews could be duplicated or omitted, depending on such factors as the ratio of actual to expected lanes open, loss of interviewing time due to bad weather, and nonresponse.

A detailed description of the development of the four stages of the sample design, to-gether with a discussion of the mathematical expressions involved, is included in appendix A. A discussion of the reliability of the re-sults in included in appendix B.

In developing the statistical sample design the Port Authority enlisted the aid of Mr. S. T. Hitchcock and Mr. Nathan Lieder of the Bureau of Public Roads and Dr. Leslie Kish of the Survey Research Center of the Univer-sity of Michigan. Dr. Kish served as statis-tical consultant during the entire conduct of the 1958 survey.

### Field interview form

The field interview form was designed to accomplish two basic purposes: To facilitate quick and accurate recording of information obtained in the interviews; and to simplify the coding of this information for punch-card processing. After considerable field testing a form was developed which provided ample space for recording eight interviews on each sheet but also permitted a considerable amount of the required information, common to all eight interviews, to be recorded only once.

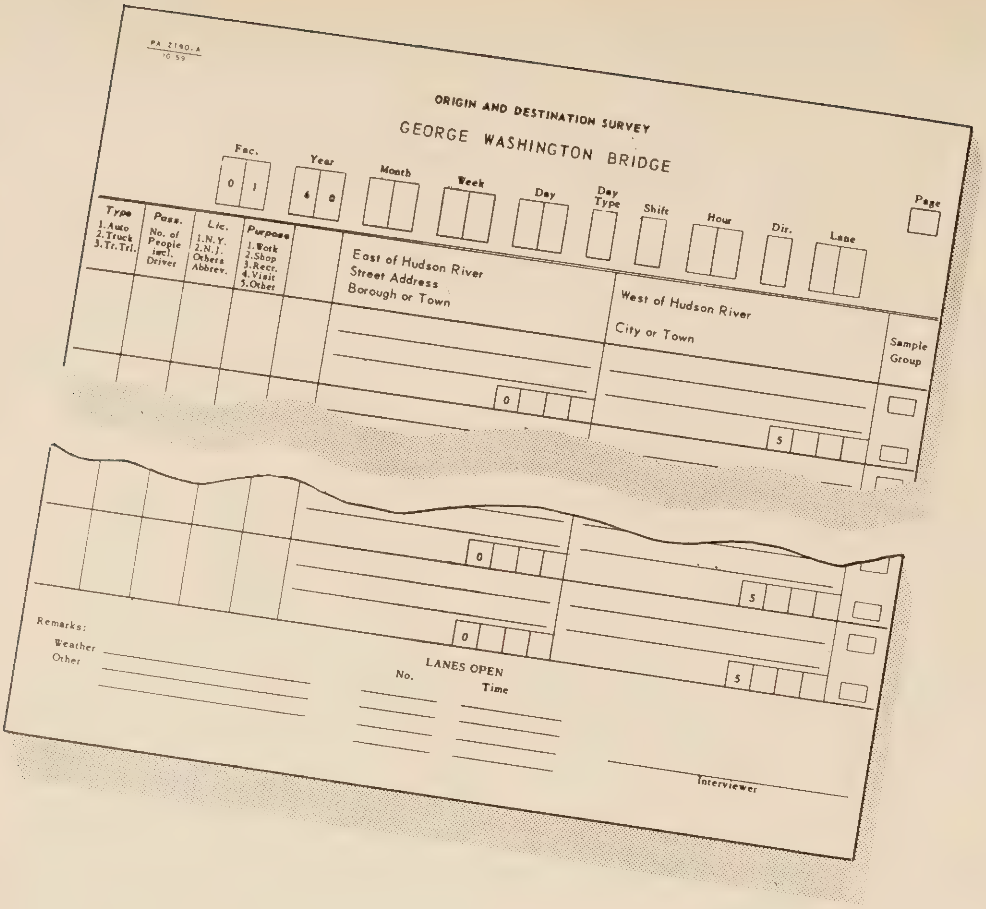


*Figure 1.—The interview questionnaire.*

The top and bottom of the form are shown in figure 1. The actual form had eight sections for recording individual trip information.

## THE 1958 SURVEY RESULTS

### *Average Daily Traffic*

The average daily traffic volumes carried by the three Hudson River crossings of the Port of New York Authority—the Holland and Lincoln Tunnels and the George Washington Bridge—are shown in table 1, classified by facility, type of day, and type of vehicle. These figures, recorded as actual counts at the facilities, reached an impressive grand total of 80.7 million motor-vehicle crossings in 1958.

The 1958 origin and destination survey included automobiles and trucks using the three trans-Hudson crossings, but did not cover buses. It must be kept in mind, therefore, that the percentage figures shown in the tables and charts that follow apply to automobiles and trucks only, and cannot be applied to bus traffic.

### *Trip Origins and Destinations*

The great majority of vehicles crossing the Hudson River in 1958 via the 3 Port Authority facilities had at least 1 terminus of their journey in the 18-county New York-New Jersey metropolitan area. This area included the 5 boroughs of New York City, 9 counties in northern New Jersey, and 4 counties in "upstate" New York and Long Island. Their locations appear in figure 2. The relative locations of the three trans-Hudson crossings are shown in figure 4 on page 92.

As shown in table 2, on weekdays 83 percent of the trans-Hudson vehicle trips were wholly within the metropolitan area, 14 percent either began or ended within the area, and only 3 percent passed through on the way to and from points outside of the area. On Sundays the intra-metropolitan area trips dropped to less than 78 percent of the total, with corresponding increases to 19 percent in trips with one terminus outside of the area and to 4 percent in the through traffic.

On both weekdays and Sundays the George Washington Bridge handled the major share of the trans-Hudson trips which had both ends outside of the metropolitan area. Presumably this reflects the role of the New Jersey Turnpike in handling this traffic, most of which is oriented in a southwest-northeast direction. There was a very close similarity in the distribution of trips through the Lincoln and Holland Tunnels, as between these three basic categories of origins and destinations. The two tunnels handled very little of the traffic passing entirely through the metropolitan area on weekdays.

A segregation of the total trans-Hudson vehicle trips into those originating or terminating in each county, as shown in figure 2, indicated that the Manhattan CBD (central business district) accounted for the largest share of the traffic in 1958—a third of the weekday total. It also showed that west of the Hudson River three counties—Bergen, Hudson, and Essex—produced nearly two-thirds of the total trans-Hudson weekday trip origins and destinations.

The analysis also illustrated the significant differences that existed between weekday and Sunday traffic patterns. East of the Hudson River, 49 percent of the total trans-Hudson vehicle trips began or ended in Manhattan on the average weekday in 1958; on Sundays, however, this proportion dropped sharply to 38 percent. Without exception, all of the other areas east of the Hudson River accounted for larger proportions of the total traffic on Sundays than on weekdays. West of the Hudson River, the traffic patterns also shifted toward the periphery on Sundays. Traffic to and from the core area, particularly Hudson County, dropped sharply on Sundays, whereas both the northern area and southern area experienced large Sunday increases as compared with their weekday share of the traffic.

#### Lines of travel

In order to get a reasonably accurate picture of the primary lines of travel of the 1958 trans-Hudson traffic and to array the many different trip origins and destinations covered in the survey into patterns that would aid in determining the points of greatest trans-Hudson traffic demand, the trips were segregated into 30 different lines of travel between

**Table 1.—Average daily motor-vehicle traffic in 1958 at 3 Hudson River crossings, by day of week and type of vehicle** [1]

| Type of day at crossing | Automobiles | Trucks | Total automobiles and trucks | Buses | Total all vehicles |
|---|---|---|---|---|---|
| George Washington Bridge: | | | | | |
| All days | 88, 840 | 6, 843 | 95, 683 | 1, 754 | 97, 437 |
| Weekdays | 84, 002 | 8, 966 | 92, 968 | 2, 008 | 94, 976 |
| Saturdays | 94, 358 | 2, 880 | 97, 238 | 1, 236 | 98, 474 |
| Sundays | 105, 695 | 1, 241 | 106, 936 | 1, 129 | 108, 065 |
| Lincoln Tunnel: | | | | | |
| All days | 52, 889 | 9, 053 | 61, 942 | 6, 236 | 68, 178 |
| Weekdays | 50, 343 | 12, 239 | 62, 582 | 6, 740 | 69, 322 |
| Saturdays | 58, 100 | 2, 665 | 60, 765 | 5, 416 | 66, 181 |
| Sundays | 60, 114 | 1, 068 | 61, 182 | 4, 766 | 65, 948 |
| Holland Tunnel: | | | | | |
| All days | 41, 523 | 13, 701 | 55, 224 | 357 | 55, 581 |
| Weekdays | 37, 581 | 18, 660 | 56, 241 | 347 | 56, 588 |
| Saturdays | 47, 976 | 3, 184 | 51, 160 | 412 | 51, 572 |
| Sundays | 53, 575 | 1, 954 | 55, 529 | 345 | 55, 874 |
| Three crossings combined: | | | | | |
| All days | 183, 252 | 29, 597 | 212, 849 | 8, 347 | 221, 196 |
| Weekdays | 171, 926 | 39, 865 | 211, 791 | 9, 095 | 220, 886 |
| Saturdays | 200, 434 | 8, 729 | 209, 163 | 7, 064 | 216, 227 |
| Sundays | 219, 384 | 4, 263 | 223, 647 | 6, 240 | 229, 887 |

[1] From actual counts at the facilities.

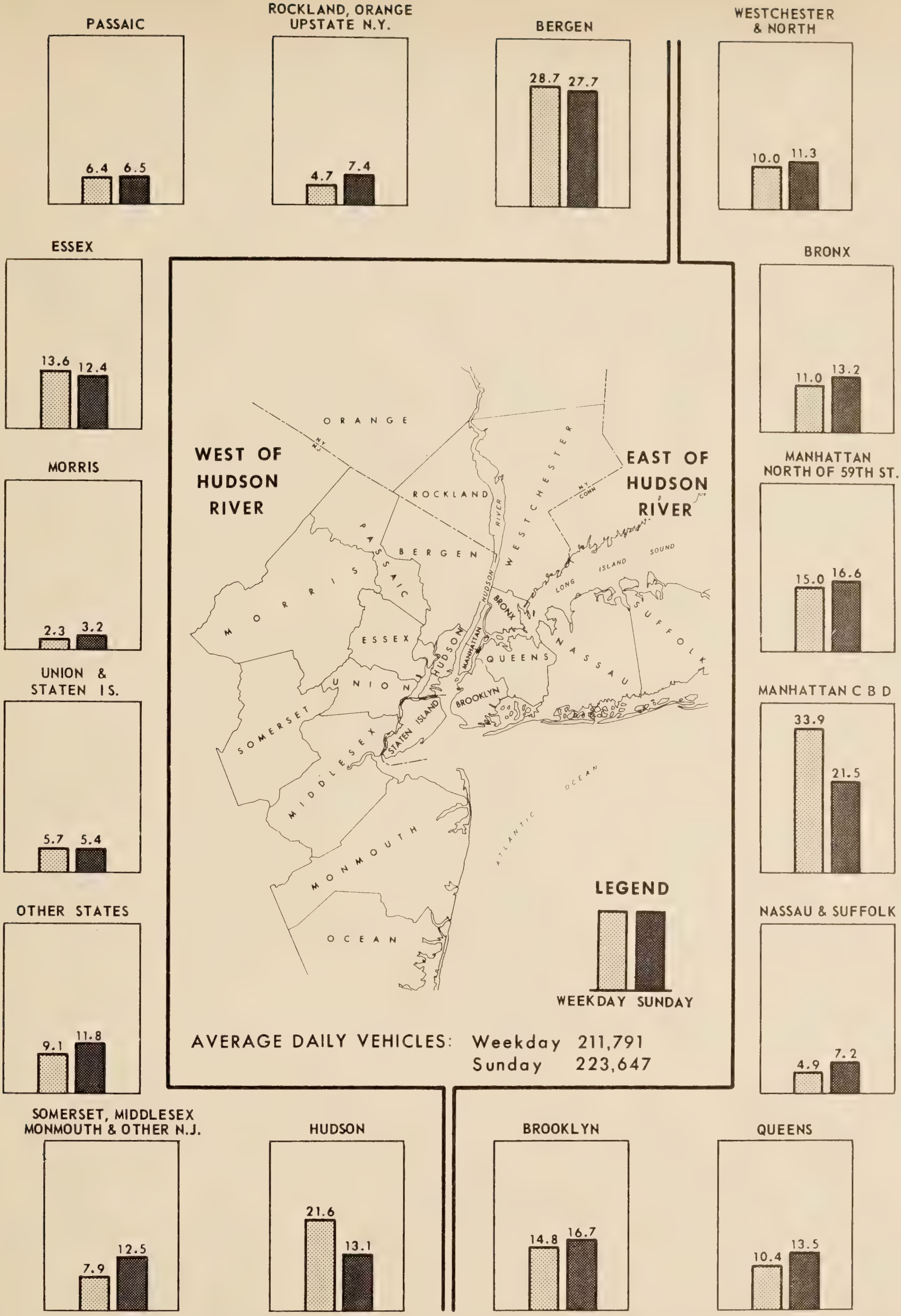


*Figure 2.—Percentage distribution of origins and destinations of trans-Hudson traffic by counties on average weekdays and Sundays in 1958.*

**Table 2.—Percentage distribution of trans-Hudson vehicle trips in 1958 by facility and by trip origin and destination in relation to the metropolitan area**

| Crossing | Percentage distribution by facility | | Percentage distribution according to trip end | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Weekdays | | | Sundays | | |
| | Weekdays | Sundays | Both ends in area | One end outside | Both ends outside | Both ends in area | One end outside | Both ends outside |
| George Washington Bridge | 43.9 | 47.8 | 80.4 | 13.5 | 6.1 | 77.1 | 15.8 | 7.1 |
| Lincoln Tunnel | 29.6 | 27.4 | 86.0 | 13.6 | .4 | 78.2 | 21.2 | .6 |
| Holland Tunnel | 26.5 | 24.8 | 85.1 | 14.3 | .6 | 77.1 | 22.3 | .6 |
| Three crossings combined | 100.0 | 100.0 | 83.4 | 13.7 | 2.9 | 77.5 | 18.8 | 3.7 |

6 zones west of the Hudson River and 5 east of the river. This is shown in table 3.

Examination of the data indicates again the considerable difference between weekday and Sunday traffic patterns in many cases. Weekday patterns are oriented much more closely around the Manhattan CBD and the central area of New Jersey. For example, trips between the Manhattan CBD and Hudson County, which comprised 9 percent of the total trans-Hudson trips on weekdays, dropped to 4 percent on Sundays. Sunday patterns tend more toward the outlying areas, emphasizing the desirability of peripheral routes. If peripheral traffic is considered as those vehicles which have neither origin nor destination in the Manhattan CBD or in Hudson County, the peripheral traffic accounted for 53 percent of the total on weekdays and 69 percent on Sundays.

### Choice of crossing

In figure 3, trans-Hudson traffic of an annual average day in 1958 has been further grouped into nine basic lines of travel in order to show how traffic over each of the nine lines was distributed among the three Hudson River crossings. The origin-destination groupings used were as follows: Northwest—Bergen, Passaic, and north; Central West—North Hudson, Essex, and Morris; Southwest—Union, South Hudson, and south; Northeast—Manhattan north of 59th St., Bronx, and north; Central East—Manhattan from Houston St. to 59th St., Queens, Nassau, and Suffolk; Southeast—Manhattan south of Houston St., and Brooklyn.

It can be seen that most of the traffic over the three east-west lines of travel (northwest-northeast, central west-central east, and southwest-southeast) used the closest facility. The choice of facility made by vehicles traveling over the diagonal lines of travel, however, reflected to a considerable extent the highways available. Thus, 66 percent of the traffic moving over the southwest-northeast line used the George Washington Bridge—the most northerly of the three crossings—and proceeded up and down the Hudson River on the west side, probably utilizing the New Jersey Turnpike. On the other hand, over the northwest-southeast line of travel, 56 percent used the George Washington Bridge and only 44 percent traveled west of the river, a reflection of the fact that there was no really good express route west of the river oriented in a northwest-southeast direction.

### Truck origins and destinations

Truck traffic over the three Hudson River crossings in 1958 constituted about 18 percent of the total weekday traffic. At the Holland Tunnel approximately one-third of the weekday vehicles were trucks. Since the average truck uses as much crossing capacity as at least two automobiles, it can be said that nearly 50 percent of the Holland Tunnel weekday capacity and 30 percent of the combined weekday capacity of the three Hudson River crossings was utilized by trucks.

In view of the importance of these truck movements from a capacity standpoint, a separate analysis was made of weekday truck origins and destinations. The analysis showed a considerably greater concentration of truck origins and destinations than was the case for automobiles. East of the river, nearly 41 percent of the trans-Hudson truck trips began or ended in the Manhattan CBD, with 15 percent destined to or from the area below Houston Street, 15 percent from Houston to 34th Street, and 11 percent fro 34th to 59th Street. Another 20 perce had origins or destinations in Brooklyn an 15 percent in Queens and Long Island.

West of the Hudson River, Hudson Count was the largest generator of truck traffi nearly 36 percent of the weekday trans-Hu son truck trips started or finished in th county and Staten Island. More than ha of these trips were destined to or from tl Manhattan CBD, with a fairly even split i route between the Holland and Lincoln Tu nels. Approximately 15 percent of the truc trip origins and destinations west of the riv were found in Essex County, with a conce tration of these in Newark.

There is a certain amount of ambiguity i these Hudson and Essex County truck tri figures. A number of over-the-road truc terminals located in those counties were use as break-bulk points or places where a chang was made from an over-the-road to a loc driver. Thus, an undetermined number truck trips which appeared to originate terminate in Hudson and Essex Counti probably were over-the-road trips or we carrying over-the-road freight. In this co nection, it is interesting to note that 20 pe cent of the truck trips over the three Po Authority Hudson River crossings in 195 had either their origin or destination ou side of the Port District, and about 3 pe cent were through trips having both origi and destination outside. Comparative fi ures for automobiles were 12 percent and percent, respectively.

The geographic distribution of truck tri movements is shown in figure 4.

## *Trends in Origin-Destination Patterns*

To utilize origin-destination informatio in planning for future vehicular needs, it i necessary to obtain not only a knowledg of current traffic patterns but also an unde standing of the trends that have developed i these patterns, particularly in the postwa years. These trends can then be related t shifts in the geographic concentrations population and industry which have take place in the past within the metropolita area and are expected to occur in the futur and forecasts of future origin and destinatio patterns can thus be produced.

**Table 3.—Percentage distribution of trans-Hudson vehicle trips in 1958 among 30 primary lines of travel**

| To or from zones west of Hudson River | To or from zones east of Hudson River | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Brooklyn | | Manhattan CBD | | Upper Manhattan | | Queens, Nassau, Suffolk | | Bronx, Westchester, upper N.Y., New England | | Total east of Hudson River | |
| | Weekday | Sunday | Weekday | Sunday | Weekday | Sunday | Weekday | Sunday | Weekday | Sunday | Weekday | Sunday |
| West Bergen, Passaic, Rockland, Orange, other north | 3.2 | 5.2 | 7.7 | 5.2 | 5.0 | 5.2 | 3.4 | 5.1 | 5.4 | 6.1 | 24.7 | 26.8 |
| East Bergen | 1.1 | 1.5 | 4.5 | 2.6 | 4.1 | 3.9 | 1.6 | 2.7 | 3.8 | 4.5 | 15.1 | 15.2 |
| Morris, Essex | 2.9 | 2.9 | 6.0 | 3.9 | 1.8 | 2.5 | 2.6 | 3.4 | 2.6 | 2.9 | 15.9 | 15.6 |
| North Hudson | 1.6 | 1.1 | 4.3 | 1.8 | 1.0 | 1.0 | 1.6 | 1.2 | 1.4 | 1.1 | 9.9 | 6.2 |
| South Hudson, Staten Island | 2.9 | 1.3 | 4.7 | 2.3 | 1.1 | 1.0 | 1.8 | 1.4 | 1.6 | 1.4 | 12.1 | 7.4 |
| Union, Somerset, Middlesex, Monmouth, other N.J., other States | 3.5 | 4.9 | 6.3 | 5.3 | 2.0 | 3.5 | 4.2 | 6.7 | 6.3 | 8.4 | 22.3 | 28.8 |
| Total west of Hudson R. | 15.2 | 16.9 | 33.5 | 21.1 | 15.0 | 17.1 | 15.2 | 20.5 | 21.1 | 24.4 | 100.0 | 100.0 |

In identifying trends in trans-Hudson trip rigin-destination patterns, through compari-on of the 1958 continuous survey results ith the results of the "one-shot" surveys of 949 and 1956, it was necessary to keep in nind that certain statistical variations would ccur which do not reflect basic trend changes. The following discussion of trends, therefore, is concentrated primarily on those changes that showed up over the whole period from 1949 to 1958 rather than on changes that appeared only between 1956 and 1958. Because a substantial number of vehicles crossed the Hudson River by ferry in 1949, such vehicle trips were included in the 1949 figures.

### General changes

Comparison of the 1958 and 1949 traffic data, presented in table 4, showed that without exception traffic originating or ter-

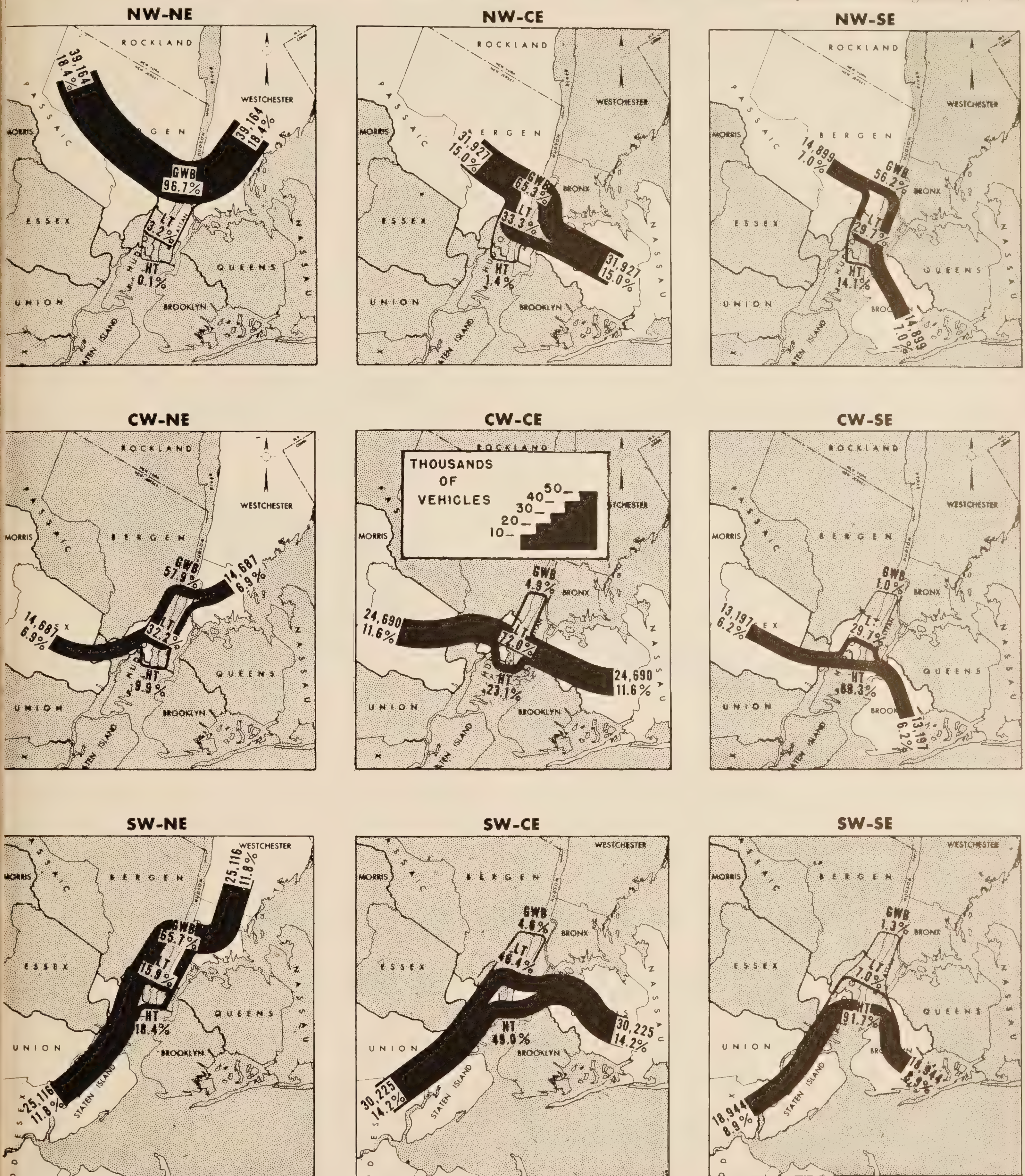


*Figure 3.—Percentage distribution of trans-Hudson vehicular traffic in 1958 over nine primary lines of travel, by facility used.*

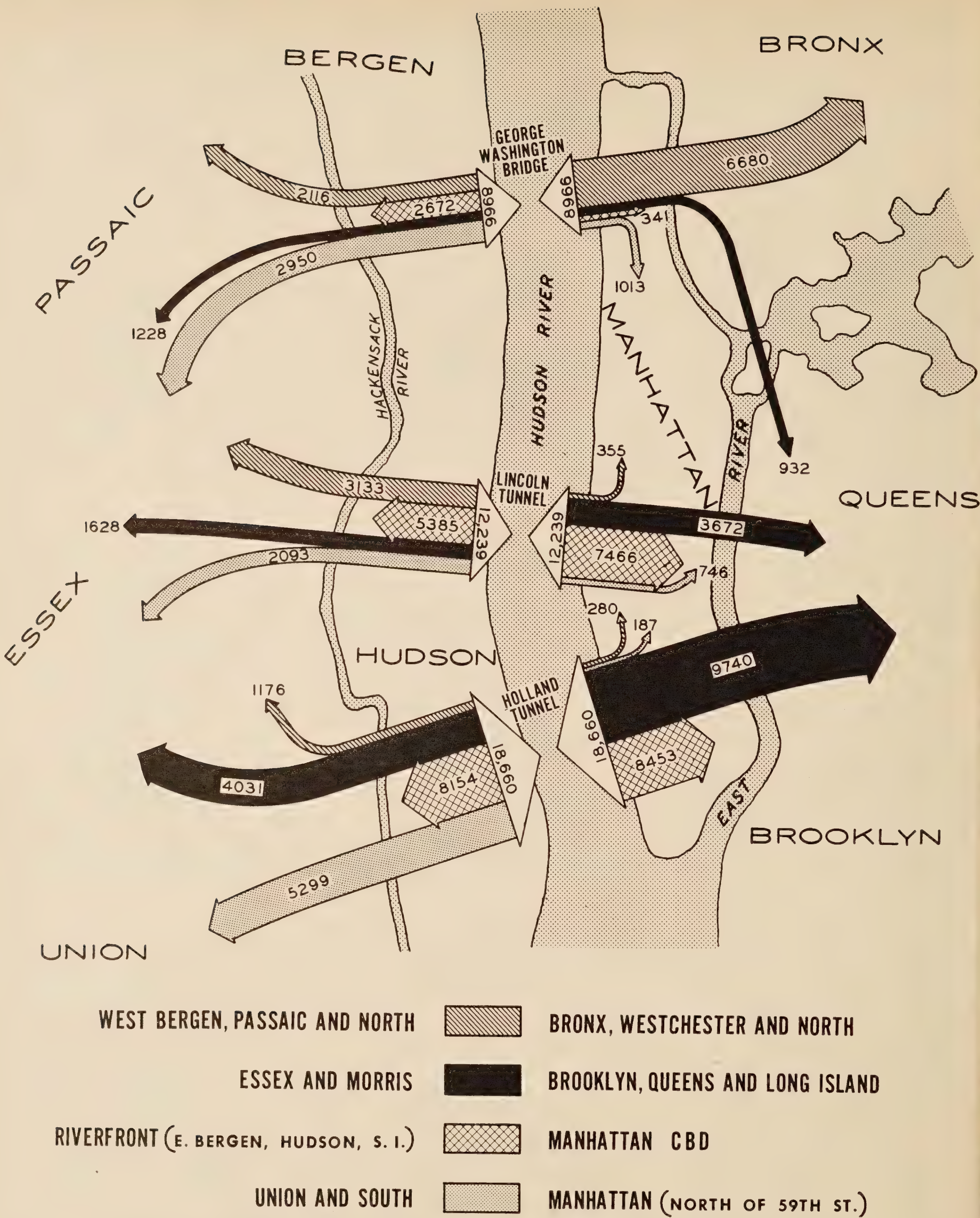


*Figure 4.—Geographic distribution of trans-Hudson truck traffic on an average weekday in 1958.*

**Table 4.—Trends in trans-Hudson vehicular trips on weekdays and Sundays, 1949–58, according to origin and destination**

| Area of origin or destination | Number of vehicle trips | | | | | | Percentage distribution | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Average weekday | | | Average Sunday | | | Weekdays | | Sundays | |
| | 1949 [1] | 1958 | Increase [2] | 1949 [1] | 1958 | Increase [2] | 1949 [1] | 1958 | 1949 [1] | 1958 |
| East of Hudson: | | | *Percent* | | | *Percent* | | | | |
| Manhattan CBD | 52,525 | 71,797 | 36.7 | 33,697 | 48,084 | 42.7 | 39.3 | 33.9 | 21.4 | 21.5 |
| Manhattan north of 59th St. | 17,776 | 31,769 | 78.7 | 24,363 | 37,126 | 52.4 | 13.3 | 15.0 | 15.5 | 16.6 |
| Subtotal Manhattan | 70,301 | 103,566 | 47.3 | 58,060 | 85,210 | 46.8 | 52.6 | 48.9 | 36.9 | 38.1 |
| Bronx | 13,365 | 23,297 | 74.3 | 22,939 | 29,521 | 28.7 | 10.0 | 11.0 | 14.1 | 13.2 |
| Westchester and north | 12,162 | 21,179 | 74.1 | 19,143 | 25,272 | 32.0 | 9.1 | 10.0 | 12.4 | 11.3 |
| Brooklyn | 20,048 | 31,345 | 56.3 | 27,844 | 37,349 | 34.1 | 15.0 | 14.8 | 17.7 | 16.7 |
| Queens | 13,232 | 22,026 | 66.5 | 20,883 | 30,192 | 44.6 | 9.9 | 10.4 | 13.2 | 13.5 |
| Nassau, Suffolk | 4,544 | 10,378 | 128.4 | 9,334 | 16,103 | 72.5 | 3.4 | 4.9 | 5.7 | 7.2 |
| Total east of Hudson R. | 133,652 | 211,791 | 58.5 | 158,203 | 223,647 | 41.4 | 100.0 | 100.0 | 100.0 | 100.0 |
| West of Hudson R.: | | | | | | | | | | |
| Rockland, Orange, upstate N.Y. | 7,752 | 9,954 | 28.4 | 16,453 | 16,550 | .6 | 5.8 | 4.7 | 10.4 | 7.4 |
| Bergen | 27,800 | 60,784 | 118.6 | 33,222 | 61,950 | 86.5 | 20.8 | 28.7 | 21.5 | 27.7 |
| Passaic | 10,291 | 13,555 | 31.7 | 12,182 | 14,537 | 19.3 | 7.7 | 6.4 | 7.6 | 6.5 |
| Hudson | 35,016 | 45,747 | 30.6 | 22,939 | 29,298 | 27.7 | 26.2 | 21.6 | 15.7 | 13.1 |
| Essex | 24,057 | 28,804 | 19.7 | 24,838 | 27,732 | 11.7 | 18.0 | 13.6 | 15.4 | 12.4 |
| Morris | 2,673 | 4,871 | 82.2 | 5,379 | 7,157 | 33.1 | 2.0 | 2.3 | 3.3 | 3.2 |
| Union, Staten Island | 7,084 | 12,072 | 70.4 | 9,018 | 12,077 | 33.9 | 5.3 | 5.7 | 5.6 | 5.4 |
| Middlesex, Monmouth and other N.J. | 8,955 | 16,731 | 86.8 | 16,611 | 27,956 | 68.3 | 6.7 | 7.9 | 10.1 | 12.5 |
| Other States | 10,024 | 19,273 | 92.3 | 17,561 | 26,390 | 50.3 | 7.5 | 9.1 | 10.4 | 11.8 |
| Total west of Hudson R. | 133,652 | 211,791 | 58.5 | 158,203 | 223,647 | 41.4 | 100.0 | 100.0 | 100.0 | 100.0 |

[1] Includes vehicles on Hudson River ferries. [2] 1958/1949.

minating in each of the counties in the metropolitan area had increased both on weekdays and on Sundays. There were, however, marked differences in the amount of growth produced in the different counties, particularly on weekdays and in those counties located west of the Hudson River. In general, as might be expected from the population and industry trends in the metropolitan area, the traffic growth was most pronounced in the outlying counties, with the areas in the core lagging behind. This, of course, emphasizes the growing importance of peripheral facilities and routings, especially since future population and industry growth in the metropolitan area is expected to be concentrated in the outlying areas.

West of the Hudson River, Bergen, Morris, and Union Counties and areas to the south and west of Union all have shown greater than average increases in weekday trans-Hudson trip origins and destinations since 1949. The older counties of Hudson, Essex, and Passaic, in contrast, recorded substantially less than average growth during this period. This is particularly significant because, next to Bergen County, these three older counties have been the largest trans-Hudson traffic generators west of the river.

Although average Sunday trans-Hudson traffic has risen more slowly since 1949 than has the average weekday traffic (41 percent for Sundays as compared with 59 percent for weekdays) substantially the same differential growth trends which occurred on weekdays in the counties west of the Hudson River also took place on Sundays. Thus, Sunday traffic volumes to and from the outlying areas, particularly Bergen, Middlesex, Monmouth, and the south, had high growth rates whereas Hudson, Essex, and Passaic had less than average increases.

East of the Hudson River, weekday traffic to and from the Manhattan CBD has increased considerably less than the average. This, too, is significant because in 1958 the Manhattan CBD still accounted for one-third of all weekday trans-Hudson trip origins and destinations. Traffic to and from Brooklyn and Queens experienced average growth; origins or destinations in Manhattan above 59th Street, the Bronx, Westchester, and north increased at a somewhat faster than average rate; and traffic generated in Nassau and Suffolk grew at a considerably faster than average rate. As to Sunday traffic, with the exception of Nassau and Suffolk which had increases of 73 percent, all of the other counties east of the Hudson showed about an average or less than average rate of growth. It is interesting to note that in contrast to its weekday trend, the Manhattan CBD Sunday trans-Hudson origins and destinations grew at a slightly higher rate than the average amount of 41 percent over the 10-year period.

A comparison of the 1958 data with the 1956 survey data (not included in this report) showed two interesting developments which, because of their consistency in all segments of the traffic, appeared to be bona fide trend developments rather than statistical variations. In 1956, traffic to and from Orange, Rockland, and upstate New York dropped sharply as a proportion of the total trans-Hudson traffic. Presumably this was occasioned by diversions to the newly-opened Tappan Zee Bridge, the Hudson River crossing of the New York Thruway located about 15 miles north of the George Washington Bridge. In 1958, however, this segment of traffic began to rise again, both on weekdays and Sundays. It may be expected that this traffic will continue to rise as motorists become more familiar with the advantages of the Palisades Interstate Parkway route (completed August 1958), running north from the George Washington Bridge on the west side of the Hudson River.

Average Sunday trans-Hudson traffic volumes in 1958 dropped below the 1957 totals and were virtually the same as those of 1956. Comparison of the 1958 with the 1956 survey results indicated that a major reason for this poor Sunday record was a substantial drop in traffic to and from points outside of the metropolitan area to the south and west and the northeast. After increasing from 15 percent of the Sunday traffic in 1949 to 21 percent in 1956, vehicle trips originating or terminating in areas south and west of the metropolitan area declined to 17 percent in 1958. Similarly, vehicle trips destined for New England and upstate New York east of the Hudson River accounted for 6.7 percent of total Sunday trans-Hudson traffic in 1949, 7.5 percent in 1956, but only 6.5 percent in 1958. It is very likely that both the recession and the abnormally poor weather in 1958 contributed to this drop in the relatively long-haul Sunday traffic, and it is to be expected that the 1959 survey results will show a resurgence in this traffic.

### Truck trip trends

Weekday trans-Hudson truck traffic increased only 23 percent from 1949 to 1958, as compared with the 59 percent growth in total trans-Hudson traffic over the same period. Changes in truck origin and destination patterns since 1949 also were less pronounced than those shown for all vehicle trips combined. The dominant fact revealed by analysis of truck trends, however, is that, despite this relative stability, the truck trends show the same tendency found in the analysis of total trans-Hudson traffic volumes: a lessening of the importance of the core areas and increased importance of the outlying areas as traffic-generators.

The distributions of truck trip origins and destinations in 1949 and in 1958 are shown in table 5. East of the Hudson River, 47 percent of the weekday truck trips originated or terminated in the Manhattan CBD in 1949, but this figure had declined to 41 percent in 1958.

**Table 5.—Trends in weekday trans-Hudson truck trips, 1949–58, according to origin and destination [1]**

| Area of origin or destination | Percentage distribution in— | |
|---|---|---|
| | 1949 [2] | 1958 |
| East of Hudson R.: | | |
| Manhattan CBD | 46.5 | 40.6 |
| Manhattan, north of 59th St. | 5.4 | 5.0 |
| Bronx | 7.7 | 7.7 |
| Westchester | 3.0 | 3.8 |
| Brooklyn | 19.1 | 20.2 |
| Queens | 10.6 | 11.1 |
| Nassau, Suffolk | 2.6 | 4.2 |
| Upper N.Y. and N. Eng. | 5.1 | 7.4 |
| Total east of Hudson R. | 100.0 | 100.0 |
| West of Hudson R.: | | |
| Orange, Rockland, upper N.Y. | 4.5 | 3.1 |
| Bergen | 9.7 | 12.5 |
| Passaic | 6.1 | 6.0 |
| Hudson | 40.4 | 35.7 |
| Essex | 17.1 | 15.5 |
| Morris | 1.1 | 1.3 |
| Union and Staten Island | 4.4 | 5.6 |
| Somerset, Middlesex, Monmouth | 4.3 | 4.5 |
| Other N.J. | 2.7 | 3.0 |
| Other States | 9.7 | 12.8 |
| Total west of Hudson R. | 100.0 | 100.0 |

[1] The average numbers of weekday truck trips were 33,446 in 1949 and 41,234 in 1958.
[2] Includes trucks on Hudson River ferries.

Manhattan north of 59th Street also experienced a modest decline in its proportionate share of the traffic. The only areas whose share of the total traffic increased substantially were Nassau and Suffolk and upper New York and New England. West of the Hudson River, the total truck traffic originating or terminating in Hudson County declined from 40 percent in 1949 to 36 percent in 1958. The total truck traffic also dropped in Essex County, from 17 percent in 1949 to 16 percent in 1958. Bergen County, in contrast, produced less than 10 percent of the truck trips in 1949 but accounted for 13 percent in 1958.

The Tappan Zee Bridge diversions and the recession and bad weather in 1958 had much the same effect on west-of-the-river truck origin and destination patterns as was observed for the total trans-Hudson traffic. Truck trips to and from Orange, Rockland, and upper New York declined from 4.5 percent of the total in 1949 to 1.9 percent in 1956 but increased to 3.1 percent in 1958. Truck trips to and from points south and southwest of the metropolitan area rose from 12.4 percent of the total in 1949 to 19.7 percent in 1956 but dropped sharply in 1958 to 15.8 percent.

### Lincoln Tunnel: Effect of third tube

The opening of the third tube of the Lincoln Tunnel in May 1957, which provided additional traffic lanes for this facility, eliminated the congestion and resulting delays which had been occurring there regularly during peak periods. The availability of this faster route through the Lincoln Tunnel resulted in both traffic-generation and diversion from other facilities, as shown by the fact that the tunnel's share of the total trans-Hudson traffic (including buses) increased from 27.7 percent in 1956 before the third tube's opening to 30.8 percent in 1958.

A special "before and after" study was made of the 1956 and 1958 survey results to measure the changes in trans-Hudson origin and destination patterns which were produced by the additional capacity at the Lincoln Tunnel. The study showed that each of the primary trans-Hudson traffic-generating areas increased its proportionate usage of the Lincoln Tunnel in 1958 but that certain of these areas experienced larger increases than others.

On an average weekday in 1958 about 41,000 automobiles, trucks, and buses destined to or from the Manhattan CBD passed through the Lincoln Tunnel. This amounted to 52 percent of the total weekday trans-Hudson vehicles with CBD origins or destinations, as compared with the 46 percent handled by the tunnel in 1956. Thus, one effect of the opening of the third tube has been to make the Lincoln Tunnel the major gateway to the central business sector of the region. As shown in table 6, the tunnel's 1958 share of the total trans-Hudson traffic (excluding buses) to and from Brooklyn, Queens, and Long Island also increased substantially over 1956. The opening of the third tube had little or no effect on the routing of traffic to or from the Bronx, Westchester, and north.

West of the Hudson River, the opening of the third tube seems to have resulted in a fairly even distribution geographically of the increases in the proportion of total traffic using the Lincoln Tunnel. All of the counties west of the river apparently were equally benefited by the elimination of delays at the Lincoln Tunnel. The primary consideration which produced variations in the amount of trans-Hudson traffic diverted to the tunnel in 1958 appears to have been the relative advantages afforded by the three-tube tunnel in serving the different points of origin or destination on the east side of the river.

**Table 6.—Percentage of total trans-Hudson vehicular traffic which used the Lincoln Tunnel, 1956–58**

| Area of origin or destination | 1956 | 1958 |
|---|---|---|
| East of Hudson R.: | *Pct.* | *Pct.* |
| Manhattan CBD | [1] 42.2 | [1] 47.5 |
| Manhattan, north of 59th St | 19.2 | 22.9 |
| Bronx | 5.9 | 5.1 |
| Westchester | 5.4 | 6.0 |
| Brooklyn | 17.0 | 22.2 |
| Queens | 32.3 | 39.2 |
| Nassau | 25.2 | 32.7 |
| Suffolk | 23.2 | 32.2 |
| Upper N.Y. and N. Eng | 6.5 | 4.2 |
| Total east of Hudson R | 26.1 | 29.5 |
| West of Hudson R.: | | |
| Orange, Rockland, upper N.Y | 6.7 | 11.3 |
| Bergen | 13.1 | 15.1 |
| Passaic | 42.9 | 47.1 |
| Hudson | 33.6 | 40.4 |
| Essex | 30.9 | 35.8 |
| Morris | 49.6 | 52.7 |
| Union and Staten Island | 25.1 | 26.4 |
| Somerset | 26.0 | 29.6 |
| Middlesex | 30.8 | 34.3 |
| Monmouth | 34.3 | 35.2 |
| Other N.J. and other States | 26.7 | 30.3 |
| Total west of Hudson R | 26.1 | 29.5 |

[1] If buses were included these figures would be 46 percent in 1956 and 52 percent in 1958.

**Table 7.—Percentage distributions showing seasonal variations of trans-Hudson weekday vehicular trips in 1958 among 30 primary lines of travel**

| | | To or from zones east of Hudson River | | | | | |
|---|---|---|---|---|---|---|---|
| To or from zones west of Hudson River | Season [1] | Brooklyn | Manhattan CBD | Manhattan north of 59th St. | Queens, Nassau, Suffolk | Bronx, Westchester, upper N.Y., New England | Total east of Hudson River |
| West Bergen, Passaic, Rockland, Orange, other north | 1st | 2.8 | 8.1 | 5.1 | 3.1 | 5.3 | 24.4 |
| | 2d | 3.6 | 7.7 | 5.1 | 3.4 | 5.5 | 25.3 |
| | 3d | 3.6 | 7.5 | 4.6 | 3.5 | 5.4 | 24.6 |
| | 4th | 2.8 | 7.6 | 5.2 | 3.4 | 5.3 | 24.3 |
| | Year | 3.2 | 7.7 | 5.0 | 3.4 | 5.4 | 24.7 |
| East Bergen | 1st | 1.0 | 5.4 | 4.5 | 1.3 | 4.0 | 16.2 |
| | 2d | 1.2 | 4.7 | 3.8 | 1.7 | 3.6 | 15.0 |
| | 3d | 1.1 | 4.0 | 3.9 | 1.8 | 3.6 | 14.4 |
| | 4th | 1.1 | 4.2 | 4.3 | 1.6 | 4.0 | 15.2 |
| | Year | 1.1 | 4.5 | 4.1 | 1.6 | 3.8 | 15.1 |
| Morris, Essex | 1st | 2.9 | 6.5 | 1.9 | 2.2 | 2.2 | 15.7 |
| | 2d | 2.8 | 6.0 | 1.7 | 2.9 | 2.8 | 16.2 |
| | 3d | 2.9 | 5.5 | 1.8 | 2.8 | 2.7 | 15.7 |
| | 4th | 3.0 | 6.2 | 1.6 | 2.6 | 2.5 | 15.9 |
| | Year | 2.9 | 6.0 | 1.8 | 2.6 | 2.6 | 15.9 |
| North Hudson | 1st | 1.9 | 4.5 | 1.3 | 1.7 | 1.3 | 10.7 |
| | 2d | 1.6 | 4.1 | .9 | 1.4 | 1.4 | 9.4 |
| | 3d | 1.4 | 4.0 | .9 | 1.5 | 1.5 | 9.3 |
| | 4th | 1.7 | 4.4 | 1.1 | 1.7 | 1.4 | 10.3 |
| | Year | 1.6 | 4.3 | 1.0 | 1.6 | 1.4 | 9.9 |
| South Hudson, Staten Island | 1st | 3.0 | 5.1 | 1.4 | 1.8 | 1.6 | 12.9 |
| | 2d | 2.7 | 4.6 | 1.1 | 2.0 | 1.4 | 11.8 |
| | 3d | 2.7 | 4.7 | 1.0 | 1.9 | 1.5 | 11.8 |
| | 4th | 3.1 | 4.8 | 1.1 | 1.6 | 1.7 | 12.3 |
| | Year | 2.9 | 4.7 | 1.1 | 1.8 | 1.6 | 12.1 |
| Union, Somerset, Middlesex, Monmouth, other N.J., other States | 1st | 3.2 | 6.5 | 1.8 | 4.0 | 4.6 | 20.1 |
| | 2d | 3.2 | 6.5 | 2.2 | 4.3 | 6.1 | 22.3 |
| | 3d | 4.1 | 6.1 | 2.1 | 4.6 | 7.3 | 24.2 |
| | 4th | 3.2 | 6.3 | 1.9 | 3.9 | 6.7 | 22.0 |
| | Year | 3.5 | 6.3 | 2.0 | 4.2 | 6.3 | 22.3 |
| Total west of Hudson R | 1st | 14.8 | 36.1 | 16.0 | 14.1 | 19.0 | 100.0 |
| | 2d | 15.1 | 33.6 | 14.8 | 15.7 | 20.8 | 100.0 |
| | 3d | 15.8 | 31.8 | 14.3 | 16.1 | 22.0 | 100.0 |
| | 4th | 14.9 | 33.5 | 15.2 | 14.8 | 21.6 | 100.0 |
| | Year | 15.2 | 33.5 | 15.0 | 15.2 | 21.1 | 100.0 |

[1] The seasons and the average weekday trips in each are: 1st, Jan.–Mar., 181,670 trips; 2d, Apr.–June, 217,545 trips; 3d, July–Sept., 230,889 trips; 4th, Oct.–Dec., 216,332 trips; annual average, 211,791 trips.

## *Seasonal, Daily, and Hourly Traffic Variations*

Information concerning average annua origin-destination patterns is important fo many planning purposes. It is just as im portant, however, to obtain a knowledge o peak period patterns, which provide the basi for the development of design criteria upo which the physical plans for vehicular facilitie are based. Seasonal and hourly variations ar two important indicators of peak conditions One of the great advantages of a continuou sampling type of origin-destination survey i its ability to develop such information.

### Seasonal variations

The 1958 survey was designed to provid seasonal data by dividing the survey perio into four 13-week quarters approximatel equivalent to the four seasons of the year Framed within the calendar year, January–March was labeled the first season, April–June the second, July–September the third and October–December the fourth. Analysi showed that seasonal variations did, in fact exist, particularly in traffic to and fro certain areas. The analysis also confirme the previous belief that the first and thir seasons (winter and summer) represent th extremes in seasonal variations in origin-destination patterns and that the second an fourth seasons (spring and fall) are ver similar to each other and generally fairl representative of the average annual pattern

The size of the 1958 sample on weekdays ınd the grouping of the many trips into the 30 primary lines of trans-Hudson vehicular :ravel provided sufficient data so that statisti- ·ally reliable origin-destination information vas obtained for each season of the year. The sample size for Sundays, however, while sufficient to yield reliable data on annual Sunday patterns, was too small to permit a ine analysis of Sunday traffic patterns in ·ach season. The analysis, therefore, was ·oncentrated primarily on weekday seasonal variations. It is expected that combining the 1959 origin-destination survey Sunday data vith the 1958 Sunday data will permit a ·eliable analysis of Sunday seasonal variations.

As shown in table 7, traffic to and from Manhattan accounted for 52 percent of the otal trans-Hudson weekday vehicle trips ·ast of the Hudson River during the winter first) season but dropped to 46 percent during he summer (third) period. The area of the Bronx and north, on the other hand, experi- ·nced an increase in its share of the total raffic from a winter proportion of 19 percent o 22 percent in the summer. Traffic to and rom Brooklyn, Queens and Long Island also showed modest proportional gains in summer.

West of the river, the largest variation was observed in trips to and from Union County ınd the south, which accounted for 24 per- ·ent of all trans-Hudson trips in the summer out only 20 percent in the winter. Trips oetween this area and the area of the Bronx ınd north (east of the Hudson River) experi- ·nced the largest seasonal variation, produc- ng 7.3 percent of the summer traffic but only 4.6 percent in winter. The areas adjacent to ınd west of the Hudson River—East Bergen, North and South Hudson, and Staten Island— ıll produced a smaller share of the total traffic n the summer than in the winter months. There was little noticeable seasonal variation n the other areas west of the river.

Further study of the data showed clearly hat traffic to and from Union County and he south varied seasonally even more on Sundays than on weekdays. Vehicles with origins or destinations in this area accounted or almost one-third of the total trans-Hudson rips on summer Sundays as compared with ıpproximately one-quarter of the winter Sun- lay trips. Sunday traffic between this area ınd the Bronx and north produced 9.5 per- ·ent of the summer totals and only 7.2 percent of the winter Sunday volumes.

It is presumed that the primary cause of these observed seasonal variations is that the distribution between business and nonbusi- ness trips changes markedly from season to season. These changes in purpose of trip are shown later in this report. Trips with a business purpose tend to be concentrated in the core of the metropolitan area, and it is these areas which account for a higher propor- tion of the trans-Hudson trips in the winter and nonsummer months. Nonbusiness trips, on the other hand, are oriented toward the more peripheral areas which, as a result, show higher proportions in the summer when nonbusiness trips reach their highest level. Thus, it follows that the summer months and weekends will produce the peak conditions which peripheral facilities must be designed to handle but that facilities serving the core areas should be designed for commuter peaks during the nonsummer months.

**Table 8.—Percentage distribution of weekday trans-Hudson automobile trips in 1958, showing peak-hour origin-destination patterns**

| Area of origin or destination | Both directions, 24 hours | Predominant direction | | Reverse direction | |
|---|---|---|---|---|---|
| | | 7-10 a.m. eastbound | 4-7 p.m. westbound | 7-10 a.m. westbound | 4-7 p.m. eastbound |
| East of Hudson R.: | | | | | |
| Bronx, Westchester and Manhattan north of 59th St | 21.3 | 21.9 | 21.5 | 25.4 | 23.2 |
| Manhattan CBD | 17.7 | 18.4 | 18.4 | 17.8 | 20.7 |
| Brooklyn, Queens, Long Island | 31.8 | 39.3 | 38.9 | 17.5 | 24.1 |
| | 29.2 | 20.4 | 21.2 | 39.3 | 32.0 |
| Total east of Hudson R | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| West of Hudson R: | | | | | |
| Rockland, Orange, Passaic, West Bergen, upstate N.Y | 26.7 | 31.1 | 30.9 | 30.0 | 28.4 |
| Essex, Morris | 15.7 | 12.4 | 13.3 | 15.4 | 17.2 |
| Union, south | 21.4 | 13.3 | 17.5 | 19.5 | 20.1 |
| East Bergen, Hudson, Staten Island | 36.2 | 43.2 | 38.3 | 35.1 | 34.3 |
| Total west of Hudson R | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

**Hourly variations**

Analysis of the weekday origin-destination data for 1958 by hour of the day and by direction indicated that in the future more attention must be focused on peak-hour origin and destination patterns, particularly on the east side of the Hudson River. The survey revealed that large differences existed between the average pattern for an entire weekday in both directions and the patterns which occur during peak periods in each direction. This is shown, for automobile trips only, in table 8.

On an average weekday in 1958 about 32 percent of the trans-Hudson automobile trips originated or terminated in the Manhattan CBD. During the peak periods in the predominant direction (7–10 a.m. eastbound and 4–7 p.m. westbound) this figure rose to 39 percent. Conversely, for the reverse direction during the morning peak period, westbound from 7–10 a.m., only 18 percent of the trans-Hudson automoblies originated in the CBD, and in the reverse direction during the evening peak period, 4–7 p.m. eastbound, only 24 percent terminated in the CBD.

Just the opposite trend is evident for Brooklyn and Long Island traffic. On an average weekday, this area accounted for 29 percent of the total trans-Hudson automobile trips. However, in the predominant directions of travel—eastbound in the morning peak period and westbound in the afternoon peak—Brooklyn and Long Island accounted for only about 21 percent of the total. In the reverse direction, 7–10 a.m., this area accounted for 39 percent of the westbound trans-Hudson automobile trips, and in the evening peak, 4–7 p.m., 32 percent of those eastbound. Hourly variations in traffic to and from upper Manhattan and the area of the Bronx and north were much less pronounced, although the reverse flow in some instances, especially the 7–10 a.m. westbound movement to and from the Bronx and north, accounted for a higher proportion of the total traffic than was the case for the entire 24 hours.

These variations clearly indicate the necessity of using peak origin and destination figures rather than average daily figures in planning ramps or approaches on the east side of the Hudson River. The tremendous differences in directional origin and destination patterns during the peak hours also suggest the possibility of utilizing reversible lanes on these ramps or approaches. Finally, the peak patterns show that the bulk of the New York automobile trips to New Jersey in the peak periods originate in areas outside of Manhattan whereas the majority of the peak-period New Jersey automobile trips are destined for Manhattan.

West of the Hudson River, the hourly origin and destination patterns did not generally vary as substantially from the 24-hour averages as they did east of the river. It is evident, however, that the area including Rockland, Orange, Passaic, West Bergen, and the north accounted for a higher proportion of the peak traffic volumes in both directions than it did over the entire 24 hours. In the predominant direction peak periods, eastbound in the morning and westbound in the evening, Essex and Morris Counties and the area of Union County and the south both generated a lower proportion of the trans-Hudson automobile trips than they did during the rest of the day. A plausible explanation is that relatively good commuter rail service exists in these areas. It is also worth noting that East Bergen and Hudson Counties, lying along the Hudson River, produced 43 percent of the eastbound 7–10 a.m. trans-Hudson automobile trips. This compares with a 24-hour figure for this area of 36 percent.

## *Purpose of Automobile Trips*

The experienced interviewers used during the continuous sampling survey were able, in virtually all cases, to obtain complete information from each of the motorists interviewed. Thus, reliable survey data were obtained covering such travel characteristics as purpose of trip, occupants per vehicle, and residence (State) or license plate of each vehicle. Analysis of these data can contribute materially to an understanding of the various competitive factors that produce trans-Hudson travel and particularly factors motivating the choice of mode of transportation.

A question as to purpose of trip was included in the survey in order to obtain information concerning forces that generate trans-Hudson

**Table 9.—Percentage distribution of trans-Hudson automobile trips by trip purpose**

| Trip purpose | Weekdays | Saturdays | Sundays | All days |
|---|---|---|---|---|
| George Washington Bridge: | | | | |
| Work | 62.4 | 21.7 | 9.2 | 46.1 |
| Recreation and other | 35.7 | 75.9 | 90.3 | 52.2 |
| Shopping | 1.9 | 2.4 | .5 | 1.7 |
| Lincoln Tunnel: | | | | |
| Work | 60.5 | 23.5 | 14.0 | 46.1 |
| Recreation and other | 37.1 | 72.7 | 85.4 | 51.6 |
| Shopping | 2.4 | 3.8 | .6 | 2.3 |
| Holland Tunnel: | | | | |
| Work | 67.8 | 27.1 | 10.0 | 50.1 |
| Recreation and other | 30.6 | 70.0 | 88.2 | 48.0 |
| Shopping | 1.6 | 2.9 | 1.8 | 1.9 |
| Three crossings combined: | | | | |
| Work | 63.1 | 23.5 | 10.8 | 47.0 |
| Recreation and other | 34.9 | 73.5 | 88.3 | 51.1 |
| Shopping | 2.0 | 3.0 | .9 | 1.9 |

automobile traffic volumes. The results, shown in table 9, indicate that of the total automobile trips during 1958 across the three Port Authority trans-Hudson facilities, 47 percent were made for business purposes, 51 percent were made for recreation and personal reasons, and a surprisingly small 2 percent for shopping purposes.

Of course, these figures varied according to the day of the week and the season of the year. Trips for work purposes accounted for 63 percent of the weekday trips, 24 percent of the Saturday trips, and 11 percent of the Sunday trips. Recreation and personal trips increased from a low of 35 percent on weekdays to 73 percent on Saturdays and 88 percent on Sundays. Shopping trips accounted for 2 percent on weekdays, 3 percent on Saturdays, and 1 percent on Sundays. Seasonally, the proportion of weekday trips made for work purposes varied from 68 percent during the winter months to 57 percent in the summer.

There were also variations in purpose of trips according to the trans-Hudson crossing used, particularly on weekdays. Nearly 68 percent of the weekday automobile trips through the Holland Tunnel had work as their purpose, compared with 62 percent for the George Washington Bridge and 60 percent for the Lincoln Tunnel. On Sundays 14 percent of the automobile trips through the Lincoln Tunnel had work as their purpose while only 10 percent of the Holland Tunnel and 9 percent of the George Washington Bridge trips were in connection with work. For each of the three facilities, the proportion of trips made for shopping, whether weekday or weekend, never rose above 3 percent.

On an hourly basis, the survey showed that the usual assumption that most automobile trips made between 7 and 10 a.m. and 4 and 7 p.m. are work trips was substantially true in the morning but not in the afternoon. As shown in the upper half of table 10, during the 7–10 a.m. period 87 percent of the eastbound and 86 percent of the westbound weekday automobile trips were for work purposes. In the 4–7 p.m. period, however, only 68 percent of the eastbound trips and 72 percent of the westbound trips were for business purposes. The afternoon peak-hour volumes in both directions were swelled by a considerable amount of recreation and personal traffic. This was particularly true of the eastbound movement, and when this fact is related to the afternoon peak origin and destination information already described, it becomes apparent that substantial numbers of New Jersey people are attracted to New York during these hours by the cultural and recreational activities in Manhattan.

## *State of Automobile Registration*

In order to acquire additional information as to the sources of trans-Hudson automobile traffic-generation, the State in which each automobile was registered, as shown on the license plate, was recorded. Approximately 50 percent of all of the automobiles crossing the Hudson River on Port Authority facilities on weekdays carried New Jersey license plates. Nearly 41 percent had New York plates and the remaining 9 percent were from all ove[r] the country. On Sundays the proportion o[f] New Jersey cars dropped to 46 percent, an[d] New York and other cars rose to 43 percen[t] and 11 percent, respectively.

New Jersey residents predominated amon[g] users of the Lincoln Tunnel both on weekday[s] and Sundays, as shown in table 11. Ne[w] Jersey also had a high proportion of automo[-] biles using the George Washington Bridg[e] on weekdays but a majority of New York an[d] other cars used the facility on Sundays. Us[e] of the Holland Tunnel on weekdays was mor[e] evenly balanced than the other two facilitie[s]. Surprisingly enough, however, on Sunday[s] more New Jersey than New York cars use[d] the Holland Tunnel, probably because th[e] New York commuters to New Jersey wh[o] make up a large part of the Holland Tunne[l] weekday traffic volumes are missing o[n] Sundays.

Analysis of the license plate data by hou[r] and direction yielded important informatio[n] on the characteristics of trans-Hudson auto[-] mobile travel during the commuter hours, a[s] shown in the lower half of table 10. In th[e] predominant direction, eastbound 7–10 a.m[.] and westbound 4–7 p.m., New Jersey cars wer[e] in the majority although this was more tru[e] of the morning traffic (78 percent of the total) than in the afternoon (70 percent). Th[e] actual number of New Jersey automobile[s] moving eastbound in the morning was ver[y] close to the number moving westbound in th[e] evening, indicating that the bulk of thi[s] traffic was composed of New Jersey resident[s] commuting to and from New York. In con[-] trast, however, over 30 percent more Ne[w] York cars traveled westbound in the evenin[g] peak than eastbound in the morning peak. This imbalance was even more pronounce[d] for the cars from other States.

In the reverse direction, New York car[s] predominated during the peak hours althoug[h] again this was more true in the morning tha[n] in the evening peak. The 4–7 p.m. east[-] bound automobile traffic was augmented b[y] a substantial number of New Jersey cars, mos[t] of which can be assumed from the precedin[g] analysis on purpose of trip to be nonbusines[s] vehicles. As a result, the number of auto[-] mobiles crossing the Hudson River eastboun[d] during the 4–7 p.m. peak outnumbered th[e] morning westbound flow by nearly one-third.

**Table 10.—Number and percentage distribution of weekday peak-hour trans-Hudson automobile trips in 1958 by purpose of trip and by State in which automobile was registered**

| Origin—purpose and State | Predominant direction | | | | Reverse direction | | | |
|---|---|---|---|---|---|---|---|---|
| | 7–10 a.m. eastbound | | 4–7 p.m. westbound | | 7–10 a.m. westbound | | 4–7 p.m. eastbound | |
| | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage |
| Purpose of trip: | | | | | | | | |
| Work | 15,697 | 87.4 | 13,616 | 71.7 | 12,930 | 86.2 | 13,639 | 68.4 |
| Recreation and other | 2,012 | 11.2 | 4,918 | 25.9 | 2,010 | 13.4 | 6,022 | 30.2 |
| Shopping | 251 | 1.4 | 456 | 2.4 | 60 | .4 | 279 | 1.4 |
| Total | 17,960 | 100.0 | 18,990 | 100.0 | 15,000 | 100.0 | 19,940 | 100.0 |
| State of registration: | | | | | | | | |
| New Jersey | 13,973 | 77.8 | 13,236 | 69.7 | 2,925 | 19.5 | 6,122 | 30.7 |
| New York | 3,179 | 17.7 | 4,292 | 22.6 | 11,010 | 73.4 | 12,303 | 61.7 |
| Other | 808 | 4.5 | 1,462 | 7.7 | 1,065 | 7.1 | 1,515 | 7.6 |
| Total | 17,960 | 100.0 | 18,990 | 100.0 | 15,000 | 100.0 | 19,940 | 100.0 |

## *Persons Per Automobile*

The average automobile crossing the Hudso[n] River via the three Port Authority crossings i[n] 1958 carried the driver and one passenger. The number of persons per automobile varie[d] considerably from the annual average figur[e] of 2.05, however, depending on the day of th[e] week, hour of day, direction of trip, an[d] facility used. The average load was 1.8[4] persons per automobile on weekdays, but ros[e] to 2.39 on Saturdays and 2.75 on Sundays.

Contrary to general impression, averag[e] loads during rush hours in the predominan[t] direction (7–10 a.m. eastbound and 4–7 p.m. westbound) tended to be somewhat less tha[n] nonrush-hour loads. Thus, at the Georg[e]

**Table 11.—Percentage distribution of trans-Hudson automobile trips in 1958 according to State in which automobile was registered**

| Crossing | Weekdays | | | Sundays | | |
|---|---|---|---|---|---|---|
| | New Jersey | New York | Other | New Jersey | New York | Other |
| George Washington Bridge | 49.6 | 40.5 | 9.9 | 40.2 | 47.2 | 12.6 |
| Lincoln Tunnel | 56.1 | 35.4 | 8.5 | 52.5 | 36.7 | 10.8 |
| Holland Tunnel | 44.4 | 48.0 | 7.6 | 49.8 | 39.8 | 10.4 |

Washington Bridge there was an average of 1.69 persons per automobile crossing eastbound between 8 and 9 a.m. compared with a nonrush-hour eastbound figure of 1.92. Similarly, at the Holland Tunnel an average of 1.70 persons per car traveled eastbound from 8 to 9 a.m. compared with 1.83 for the nonrush hours. The Lincoln Tunnel was the only crossing where the average rush-hour load, 1.91 persons per automobile eastbound, reached a level comparable with the nonrush-hour figure of 1.94. Presumably this is the effect of car pooling.

There is quite obviously a greater tendency for "blue-collar workers" commuting to the industrial areas in New Jersey to utilize car pools. Thus, at each Hudson River crossing, the westbound load per automobile from 7 to 8 a.m. (the peak morning hour westbound) was substantially higher than the nonpeak loads. For the three Port Authority crossings combined, there was an average of 2.04 persons per car from 7 to 8 a.m. westbound, higher than the 1.85 westbound for the nonrush hours. The fluctuations are shown in figure 5.

## Appendix A

### *Statistical Model*

The sample structure as finally designed was a four-stage probability sample in which the probability of selection of any vehicle in the universe was the product of the probabilities of selection in each stage. With this method the chance of selection of a vehicle at any one facility was the same as at any other facility. Thus, the survey results from each facility could be combined for analysis purposes. The four stages of selection were:

*Shift.*—An 8-hour work period at one of the facilities on a day of the week.

*Location.*—A geographically contiguous group of lanes at a facility at which the interviewer remains for 4 hours.

*Lane.*—One of the toll lanes within a location.

*Vehicle.*—An automobile, truck, or tractor-trailer passing through a lane. (Buses were excluded from the survey.)

A total of 572 shifts per year, or 11 for each of the 52 weeks, were chosen. It was estimated that an annual total of about 100,000 interviews would be obtained, but only 92,329 were actually made, due primarily to less than expected traffic through the facilities in 1958. The interviews covered 0.1 percent of the total of 85.7 million vehicles which crossed the facilities in 1958.

Shifts were selected in groups of two seasons each or 286 shifts for each half year. There were three basic criteria which had to be met: (1) Stratification to represent the different types of shifts properly and spread them as evenly as possible throughout each season; (2) random selection of shifts; and (3) roughly equal work loads per shift.

The first step in selecting the shifts (primary sampling units) to be covered was to construct a selection table. The table set down in orderly sequence a group of 84 strata consisting of each of the three tours of duty on each of the seven days of the week at each of the four facilities (the three Staten Island bridges were handled as one); thus, $3 \times 7 \times 4 = 84$.

Each stratum was represented by the measure $f_i$ which was proportional to the expected hourly density of traffic flow in thousands for that stratum. Each $f_i$ was made to be an integer for ease of selection and balance. The sum of the $f_i$'s for all strata was 286, divided into 143 for each of the 2 seasons. Systematic random sampling was used on the selection table to make up 13 weekly work loads of 11 shifts each, with each work load roughly spread across the strata.

The probability $Pr$ of selecting a vehicle crossing a facility may be represented as:

$$Pr = \left(\frac{11f_i}{286}\right)\left(\frac{1}{24f_i}\right)\left(\frac{44}{60}\right) = \frac{1}{851}$$

The first term denotes the probability of selecting a shift. This was the first stage of selection. Eleven shifts were selected each week with probability $f_i/286$.

The third term reflects the fact that interviewing takes place only 44 minutes out of each hour, the balance of each hour being given to relief.

The middle term represents a composite of the last three stages of selection: Location, which is the second stage; lane within location, which is the third stage; and vehicle within lane, which is the fourth or ultimate stage of selection. Thus, $Pr$ (selection within a shift) $= 1/24f_i = Pr$ (location) $\times$ $Pr$ (lane within location) $\times$ $Pr$ (vehicle within lane).

Therefore the probability or the rate for selecting a vehicle within a lane may be expressed as:

$$\frac{1}{24f_i} \times \frac{1}{Pr\text{ (location)}} \times \frac{1}{Pr\text{ (lane within location)}} = Pr\text{ (vehicle within lane)} = \frac{1}{t}$$

where $t$ is the sampling interval for a stated hour in the selected lane and is equal to the product of the denominators of the three expressions.

For example, at a facility where there were two locations and four lanes were expected to be open during a specified hour at the selected location, $Pr$ (location) $= 1/2$ and $Pr$ (lane within location) $= 1/4$. The sampling interval $t$ is equal to $24f_i \times 1/2 \times 1/4 = 3f_i$. If $f_i$ for this shift was 4, then the interviewer would select every twelfth vehicle.

Locations were selected by random procedures and balanced for relevant factors over a season. Lane rotation systems at each location were defined for all facilities in advance. Fractional intervals for selection of vehicles within lanes were made into integers by a balanced process of randomization. At all stages of selection randomized procedures were always used and carefully specified.

**Derivation of tables**

In order to simplify the use of the tables contained in this report, where only percentages were desired, it was decided to use proportions derived from the sample estimates obtained from the punch-card tabulations of the survey results. The estimates used in this report are thus ratio estimates of the form, $p = x/n$

where: $x$ = the total "self-weighting" card count of all vehicles with an "$x$" characteristic.

$n$ = the card count in the entire sample or some subclass.

These proportions can be used to estimate numbers of vehicles for any desired character-

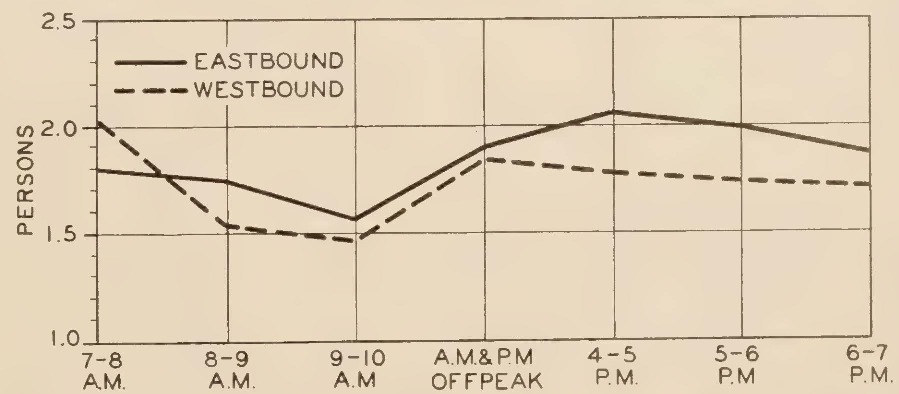


*Figure 5.—Average weekday persons per auto during peak and offpeak periods for all three river crossings combined.*

istic by application to known seasonal or annual data as follows:

$$X' = Np = N\frac{x}{n}$$

where $N$ is the known total for the characteristic under consideration.

## Appendix B

### *Reliability of Results*

Two basic types of errors are encountered in all sample surveys, to a greater or lesser degree, which affect the reliability of the survey results. The first is sampling error, which arises from the fact that the population characteristics as pictured by the sample may not exactly coincide with the characteristics which would emerge if the population were sampled in its entirety. The second is nonsampling error, which arises primarily from errors in processing the survey results and from bias in the sample due to nonresponse.

Throughout the conduct of this survey, every effort was made to keep these errors to a minimum. Furthermore, at a number of periods throughout the survey, audits of certain results of the survey were undertaken in order to compare them with recorded information of total traffic volumes by direction, by type of day, by type of vehicle, and so forth. All of these comparisons revealed close agreement between the survey results and the recorded volumes.

#### Sampling error

The distinguishing feature of a sample based on the mathematical theory of probability is the fact that it makes possible the computation of a sampling error. This gives a measure of the degree of reliability that has been attained in any particular value derived from the survey. At a given level of confidence, 95 percent, for example, the sampling error is to be interpreted as a range of values about the sample estimate which includes the "true value" in the population 95 times out of 100.

Perhaps an example in the use of sampling error will clarify its meaning. During 1958, a total of 13,357 automobile trip interviews were made on weekdays at the Lincoln Tunnel. The survey indicated that 12.2 percent of these automobiles traveled between the Manhattan CBD and areas in northwestern New Jersey and upstate New York. The theory permitted the application of this sample proportion to the entire population which, in this case, was the 12.6 million automobiles that actually used the Lincoln Tunnel on weekdays in 1958 (50,343 on an average weekday). It is true, of course, that if the origin and destination patterns of every one of these 12.6 million movements via the Lincoln Tunnel on weekdays could have been ascertained, the proportion would probably be somewhat different from the 12.2 percent mentioned above. With a probability sample it is possible, for a given level of confidence, to estimate the maximum size of this difference by establishing a range of values about this sample estimate within which the true value should lie. This range can be expressed as follows:

$$Ps \pm t_\alpha Ps(C.V.)s$$

where $Ps$ = proportion of some sub-class for characteristics $s$.

$(C.V.)s$ = coefficient of variation for characteristic $s$.

$t_\alpha$ = Student's $t$ value for four degrees of freedom and $\alpha$ error.

The coefficient of variation measures the standard deviation relative to the mean.[2] Thus in this survey,

$$(C.V.)s = \sqrt{\frac{\Sigma(Nh_1 - Nh_2)^2}{[\Sigma(Nh_1 + Nh_2)]^2}}$$

where $Nh_1$ = card count of characteristic for each of the four seasons in subsample group 1.

$Nh_2$ = card count of characteristic for each of the four seasons in subsample group 2.

To make possible the use of the above formula for the computation of the coefficients of variation, the sample was drawn in two independent subsamples for each season.

In order to make sure that the sampling error computations did not overstate the reliability of the sample, a conservative formula was used which for most cases leads to estimates of error somewhat greater than actually exist for the ratio estimates developed in this survey. Thus, the results were probably a little better than the calculated errors would indicate.

In the example already given, $Ps$ = 12.2 percent and $(C.V.)s$ = 0.034. For a 68-percent level of confidence the $t$ value is 1.14, and the true value in the population for the proportion of automobile trips on weekdays via the Lincoln Tunnel between the Manhattan CBD and northwestern New Jersey and upstate New York would be included in the range:

$$12.2 \pm 1.14 \times 12.2 \times 0.034 = 11.7 \text{ to } 12.7 \text{ percent}$$

For a 95-percent level of confidence the true value in the population lies in the range:

$$12.2 \pm 2.78 \times 12.2 \times 0.034 = 11.0 \text{ to } 13.4 \text{ percent}$$

[2] Kish and Hess, *On Variances of Ratios and Their Differences in Multi-Stage Samples*, Journal of the American Statistical Association, June 1959.

**Table 12.—Standard deviations for selected sample estimates**

| Sample size | Proportion of selected subclass in sample, $Ps$ | Standard deviation, $Ps\ (C.V.)s$ |
|---|---|---|
| | *Percent* | *Percent* |
| 1,353 | 75.7 | 1.5 |
| 918 | 44.2 | 2.2 |
| 2,829 | 29.0 | 1.0 |
| 5,462 | 22.0 | .9 |
| 11,745 | 14.3 | .7 |
| 10,355 | 12.7 | .6 |
| 13,357 | 12.2 | .4 |
| 5,707 | 9.5 | .4 |
| 10,355 | 6.7 | .3 |
| 22,444 | 4.3 | .2 |
| 22,444 | 3.2 | .1 |
| 13,357 | 1.8 | .1 |
| 13,357 | 1.7 | .1 |
| 6,836 | 1.7 | .1 |

Table 12 shows the standard deviations fc a series of representative estimates taken fro this report. There were literally over a mi lion estimates obtained in the course of tabu lating the survey results. The standar deviations shown are believed to be representa tive of the errors expected on any estimates i this report.

#### Nonsampling error

In sample surveys involving the questionin of people, a certain amount of nonresponse i bound to occur. The problem is to keep i within such bounds that the theory of proba bility still is valid.

As mentioned previously, there were 57 primary sampling units (8-hour shifts) picke at random throughout the year, segregated int the four seasons of 1958. Of the 572 shift originally scheduled, 60, or 10 percent, wer missed and had to be rescheduled to a nev date in the quickest possible time. All shift missed were due to the interviewer's sicknes or some other personal reason.

The proportion of shifts rescheduled fo each facility did not vary considerably from the overall percentage (10 percent); hence there was no particular bias of rescheduling against any one facility. More importan than this, most shifts were rescheduled withir a few weeks, and it is fair to assume that the general patterns of travel on the rescheduled dates were not significantly different than on the originally scheduled dates. Of course, on a few occasions, rain or snowstorms occurred on either the original or rescheduled dates, thereby probably affecting the results to some small degree.

It was only in the fourth season (October–December) that any considerable rescheduling lag occurred, but even here almost 70 percent of the shifts were completed within 4 weeks of the original date. In the other three seasons at least half of the rescheduled shifts were completed within 1 week and all were completed within 4 weeks of the original date.

The number of interviews obtained on rescheduled shifts were, on the whole, greater than would have been taken on the original survey dates, the average loads being 178 and 162 interviews, respectively. However, since the procedure followed in this survey was to reweight the number of the interviews obtained on the rescheduled dates to the number which would have been obtained originally, this numerical discrepancy made no difference. The important assumption made was that the patterns of travel were not significantly different on the rescheduled dates than on the original ones. This seemed valid when the time lag for rescheduling was as small as that which occurred on the survey.

As in all sample surveys involving the questioning of people, there were some units for which no information was obtained due to refusal of motorists to answer and to other reasons. The latter, classified as noninterviewable, included those sampling units such as military vehicles, ambulances, and hearses which, although they were included in the sampling universe, could not be interviewed for obvious reasons. These two types of errors of nonresponse were treated by taking random selections from the obtained interviews in an appropriate manner.

The overall nonresponse rate experienced in this survey was only 1.5 percent of the total number of interviews taken. There was no significant difference by facility or season, the minimum being 1.0 and the maximum 2.9 percent. This is considered excellent for this type of survey and is an indication of the training in interviewing techniques which each interviewer received, as well as their patience and fortitude on the job.

Another error that occurs in surveys of this nature is due to the miscoding of the information obtained in the field. Procedures based on valid techniques of quality control were applied in the verification of coded interviews to insure acceptable standards of coding efficiency. Most of those coding errors that evaded detection and were keypunched incorrectly were discovered on checking the listing of all detail cards. Overall, processing errors of all types amounted to less than 0.2 percent.

# Properties of Highway Asphalts—Part II, Various Penetration Grades

*(Continued from page 85)*

easier. Continued research is needed to relate the engineering properties of asphalts to these fundamentals and to determine if these techniques are suitable for specification purposes.

Over the years attempts have been made to define the properties of the asphalts in terms of their chemical composition or component analysis, but often have resulted in uncertain results because of the complexity of the organic molecules present. However, research now being conducted in this area is encouraging (2, 3). New approaches with modern techniques may do much to provide fundamental information that ultimately may assist the researcher in solving the problems associated with the production and utilization of asphalts of high quality.

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# New Publications

The Bureau of Public Roads has recently published two new bulletins. One of the bulletins, *Hydraulics of Bridge Waterways*, is the first of a proposed series on hydraulic design of highway drainage structures. The 53-page illustrated publication by the Division of Hydraulic Research is available from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C., at 40 cents per copy.

*Hydraulics of Bridge Waterways* presents simplified methods for computing backwater caused by bridges, developed from extensive model tests and checked against actual measurements at bridge approaches. The empirical curves and methods of calculation contained in the new publication have been subjected to extensive field use during the past few years by State highway departments, consulting engineers, and the Bureau of Public Roads, and a number of improvements developed during this period are incorporated in the publication.

The nature of the new bulletin is indicated by the chapter titles: computation of backwater; extent of backwater; difference in level across approach embankments; dual bridges; abnormal stage-discharge condition; effect of scour on backwater; illustrative problems; and limitations of data.

As noted in the introduction to the publication, hydraulics should play an important role in establishing what the length and vertical clearance of a bridge should be, and where the bridge should be placed. Confining flood water unduly may well cause excessive backwater with resultant damage to upstream land and improvements and overtopping of the roadway, or may induce excessive scour endangering the bridge itself. Too long a bridge may cost far more than can be justified by the benefits obtained. Somewhere in between is the design that will be the most economical to the public over a long period of years, and finding that design is the objective of the bridge engineer.

The new Bureau of Public Roads publication *Hydraulics of Bridge Waterways* is intended to provide, within the limitations described, a means of computing the effect of a given bridge upon the flow of the stream it is proposed to span.

*Classification of Motor Vehicles, 1956–57*, reporting detailed information on the numbers of vehicles registered in 1956, with an estimate for 1957, classified according to type of vehicle, kind of fuel used, gross vehicle weight, and type of use—farm, nonfarm, for hire, and publicly owned—is also available from the Superintendent of Documents, U.S. Government Printing Office.

The 123-page bulletin contains a wealth of detailed information that has not been available since the truck and bus inventory undertaken in 1941 as a wartime preparedness measure. It represents a considerable effort on the parts of the States, the Bureau of Public Roads, and the bus industry, since the information in the detail compiled in this study is not available in the regular registration records of many States.

In addition to a brief, explanatory text and summary tables and illustrations, the publication contains three extensive series of tabulations which will be extremely useful to highway engineers, administrators, and economists, as well as to others interested in transportation and government. The first of these reports, by States, the numbers of vehicles classified by type, by class of use, and by kind of fuel used. The second series reports, also by States, the numbers of trucks and combinations classified by types and by gross vehicle weight groups. The third series reports, by Census divisions, the numbers of trucks and combinations classified by type, class of use, kind of fuel used, and gross vehicle weight.

A fourth series of tables reports, by States, the farm registration rates and limitations on farm registrations, in those States that have a separate farm registration classification; and the numbers of trucks and combinations registered in that classification, by type of vehicle and gross vehicle weight.

One of the problems faced in the study was the fact that the States use varying bases for weight classification in their registration systems. To overcome this difficulty a series of conversion tables were devised, for relating known empty vehicle weight to probable gross vehicle weight. The conversion tables are included in the publication, since they should be of considerable use to many who use motor-vehicle statistics in their work.

Another problem faced was that of duplication of registrations. While this occurs but little for most vehicle groups, it is a common practice for commercial buses. However, duplicate bus registrations were eliminated through the cooperation of the bus industry.

*Classification of Motor Vehicles, 1956–57* may be purchased from the U.S. Government Printing Office, Washington 25, D.C., at 70 cents per copy.



U.S. GOVERNMENT PRINTING OFFICE: 1960

# PUBLICATIONS
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*A list of the more important articles in* Public Roads *and title heets for volumes 24–30 are available upon request addressed to Bureau of Public Roads, Washington 25, D.C.*

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**ANNUAL REPORTS**

Annual Reports of the Bureau of Public Roads:
1951, 35 cents. 1952, 25 cents. 1955, 25 cents. 1958, 30 cents. 1959, 40 cents. (Other years are now out of print.)

**REPORTS TO CONGRESS**

A Report of Factors for Use in Apportioning Funds for the National System of Interstate and Defense Highways, House Document No. 300 (1958). 15 cents.

Consideration for Reimbursement for Certain Highways on the Interstate System, House Document No. 301 (1958). 15 cents.

Factual Discussion of Motortruck Operation, Regulation and Taxation (1951). 30 cents.

Federal Role in Highway Safety, House Document No. 93 (1959). 60 cents.

First Progress Report of the Highway Cost Allocation Study, House Document No. 106 (1957). 35 cents.

Highway Needs of the National Defense, House Document No. 249 (1949). 50 cents.

Interregional Highways, House Document No. 379 (1944). 75 cents.

Local Rural Road Problem (1950). Out of print.

Needs of the Highway Systems, 1955–84, House Document No. 120 (1955). 15 cents.

Progress and Feasibility of Toll Roads and Their Relation to the Federal-Aid Program, House Document No. 139 (1955). 15 cents.

Progress Report on the Federal-Aid Highway Program, House Document No. 74 (1959). 70 cents.

Public Utility Relocation Incident to Highway Improvement, House Document No. 127 (1955). 25 cents.

Third Progress Report of the Highway Cost Allocation Study, House Document No. 91 (1959). Out of print.

**PUBLICATIONS**

Catalog of Highway Bridge Plans (1959). $1.00.

Construction of Private Driveways, No. 272 MP (1937). 15 cents.

Criteria for Prestressed Concrete Bridges (1954). Out of print.

Design Capacity Charts for Signalized Street and Highway Intersections (reprint from Public Roads, Feb. 1951). 25 cents.

Financing of Highways by Counties and Local Rural Governments: 1942–51. 75 cents.

General Location of the National System of Interstate Highways, Including All Additional Routes at Urban Areas Designated in September 1955. 55 cents.

Highway Bond Calculations (1936). 10 cents.

Highway Capacity Manual (1950). $1.00.

Highway Statistics (published annually since 1945):
1955, $1.00. 1956, $1.00. 1957, $1.25. 1958, $1.00.

Highway Statistics, Summary to 1955. $1.00.

Highways of History (1939). 25 cents.

Legal Aspcets of Controlling Highway Access (1945). 15 cents.

Manual on Uniform Traffic Control Devices for Streets and Highways (1948) (*including 1954 revisions supplement*). $1.25.
Revisions to the Manual on Uniform Traffic Control Devices for Streets and Highways (1954). *Separate,* 15 cents.

Parking Guide for Cities (1956). 55 cents.

Public Control of Highway Access and Roadside Development (1947). 35 cents.

Public Land Acquisition for Highway Purposes (1943). 10 cents.

Results of Physical Tests of Road-Building Aggregate (1953). $1.00.

Selected Bibliography on Highway Finance (1951). 60 cents.

Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways, 1958: a reference guide outline. 75 cents.

Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, FP–57 (1957). $2.00.

Standard Plans for Highway Bridge Superstructure (1956). $1.75.

The Role of Aerial Surveys in Highway Engineering (1960). 40 cents.

Transition Curves for Highways (1940). $1.75

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