National Cooperative Highway Research Program

RESEARCH RESULTS DIGEST

Special Rpts

DIGEST 89 - NOVEMBER 1976

These **Digests** are issued in the interest of providing an early awareness of the research results emanating from projects in the NCHRP. By making these results known as they are developed and prior to publication of the project report in the regular NCHRP series, it is hoped that the potential users of the research findings will be encouraged toward their early implementation in operating practices. Persons wanting to pursue the project subject matter in greater depth may obtain, on a loan basis, an uncorrected draft copy of the agency's report by request to: NCHRP Program Director, Transportation Research Board, 2101 Constitution Ave., N.W., Washington, D.C. 20418

# Guidelines for Skid-Resistant Highway Pavement Surfaces

*An NCHRP staff digest of the essential findings from the final report on NCHRP Project 1-12(3), "Requirements for Wear-Resistant and Skid-Resistant Highway Pavement Surfaces," by C. J. Van Til, B. J. Carr, B. A. Vallerga and J. M. Hilliard, Materials Research and Development, Oakland, California*

## THE PROBLEM AND ITS SOLUTION

In the interest of highway safety, it is essential that new pavements be designed and constructed with surface characteristics adequate for minimizing wet-weather skidding and hydroplaning accidents during their expected service life. Procedures are also needed for correcting polished or worn surfaces. Materials engineers and others responsible for the design of pavements will find the expanded body of knowledge on pavement skid resistance characteristics contained in this report to be quite helpful during the selection of aggregates and pavement systems for new highways and the rehabilitation of existing roads. The report contains guidelines for the design and construction of the ten pavement systems considered most suitable for immediate use where greater than normal skid resistance is desired. These ten pavements are classified (Table 1) with regard to polish resistance, hydroplaning potential, effective life, cost, and recommended use. A guide has been prepared in chart form to assist in selection of a suitable pavement system for a particular location. The results of an extensive experimental program involving the exposure of 36 pavement sections to simulated traffic of up to 7,000,000 wheel passes on a circular test track generally confirm previous research and experience concerning the importance of aggregate selection to pavement skid resistance. The unlikely prospects for economical development of pavement surfaces adequately resistant to the wear effects of studded tire traffic or new and innovative procedures for improving pavement skid resistance and correcting worn and polished surfaces were also verified.

Although the project objective of identifying and testing new and innovative pavement systems for providing high levels of resistance to studded tire wear and conventional tire polishing was not achieved, the research was productive in the sense of classifying conventional skid-resistant pavement surfaces and developing guidelines for their design and construction. These are immediately implementable because they were selected on the basis of a minimum of five years of satisfactory performance in at least three full-scale field installations. The simulated traffic verification of previous research with regard to polish resistance of conventional pavements and aggregates will be useful to highway agencies desiring to:

1. Design and construct pavements with particularly high levels of skid resistance for such critical locations as intersections, sharp curves, high-speed merging lanes and approaches to toll gates.

2. Do the best possible job of providing improved wet-weather skid resistance on all roads within available funds, using existing materials.

FINDINGS

The objectives of NCHRP Project 1-12(3) were to:

1. Identify and evaluate procedures, suitable for implementation, that will improve resistance of pavements to polishing and wear caused by conventional and studded tire traffic.

2. Identify possible innovative procedures for improved wear-resistant and skid-resistant pavements.

3. Conduct an experimental program to evaluate selected procedures identified under objective 2.

The initial identification and review of both published and unpublished information on wear-resistant and skid-resistant highway pavement surfaces enabled preparation of an annotated bibliography consisting of 410 items. After identifying and classifying the various pavement systems, they were evaluated on the basis of available performance information. Ten systems were selected as being most suitable for immediate practical application. The major criterion used in the selection process was at least five years of satisfactory performance in at least three full-scale field applications. The selected systems were judged to be capable of producing satisfactory initial macrotexture to inhibit hydroplaning at normal operating speeds and provide minimum loss of skid resistance with increasing speed. All are suitable for normal exposure categories such as most city streets and rural highways with no steep grades, sharp curves, or unusual hazards. Several of the more costly systems are suitable for use in special or critical exposure areas such as intersections, sharp curves, merging lanes, approaches to toll gates, and high-speed urban expressways.

The ten systems selected as most suitable for implementation as skid-resistant pavement surfaces are described briefly as follows:

1. Portland cement concrete with sharp, polish-resistant fine aggregate and coarse-texture (tined) surface.

2. Dense-graded asphaltic concrete with polish-resistant coarse aggregate.

3. Open-graded asphaltic concrete with polish-resistant coarse aggregate.

4. Gap-graded asphaltic concrete with polish-resistant coarse aggregate.

5. Asphaltic concrete with rolled-in, precoated, polish-resistant chips.

6. Epoxy-modified asphaltic concrete with polish-resistant coarse aggregate.

7. Asphalt seal coat with polish-resistant chips.

8. Rubberized asphalt seal coat with polish-resistant chips.

9. Asphalt seal coat with calcined bauxite chips.

10. Sawed longitudinal grooves in existing portland cement concrete.

The report contains guidelines for use of each of the systems, including applicable type and condition of pavement, applicable traffic conditions, expected performance, recommended laboratory and field work, and suggestions for specifications of materials and construction.

Because aggregates comprise more than 90 percent of a pavement mixture, their selection is of primary importance in the design of skid-resistant pavements. Some empirical correlations between aggregate type and polish resistance of pavements exposed to conventional traffic have been developed at local levels. However, the relationship of measurable aggregate characteristics to pavement skid resistance have not been well established. The only laboratory test with a reasonable history of correlation with pavement skid resistance is the Polished Stone Value (PSV) developed by the Transportation and Road Research Laboratory of Great Britain. In the absence of generally accepted test methods for aggregates to be used in skid-resistant pavement surfaces, the following five descriptive groupings are suggested for the purpose of identifying potentially promising aggregates for the desired level of service.

Group I - Outstanding Polish Resistance. Aggregates in this group are heterogeneous combinations of hard minerals with a coarse-grained microstructure of hard particles bonded together with a slightly softer matrix. Examples are calcined bauxite (synthetic), emery (natural), and others used by the grinding-wheel industry. Because of the high cost, practical use is limited to small areas at critical locations.

Group II - Above-Average Polish Resistance. This group comprises a minority of aggregate types used for highway paving, including blast furnace slags and expanded shales (synthetic) and crushed sedimentary rocks such as sandstone, arkose, graywacke, and quartzite (natural). When durability and abrasion resistance is acceptable and where readily available, these aggregates are suitable and practical for use in surface courses of high traffic volume roadways.

Group III - Average Polish Resistance. This group consists of many of the aggregates currently used in pavement construction, including crushed, dense igneous and metamorphic rocks of the granite, granite gneiss, and diorite types. In pavement surfaces they produce satisfactory skid resistance for all but the most severe conditions.

Group IV - Below-Average Polish Resistance. All remaining aggregates except those in Group V are included in this group. Although polish resistance is below average, they are considered acceptable for low traffic volume pavement surfaces and locations where skid resistance requirements are below normal.

Group V - Low Polish Resistance. Typical in this group are carbonate aggregates containing low levels of siliceous material and uncrushed gravels. The initial skid resistance of pavement surfaces built with these aggregates is likely to be high, but polishing increases in direct relation to traffic exposure. Their use as the primary aggregate in surface courses should be avoided for other than low traffic volume roads operated at low to moderate speeds and pavements of a temporary or short-term nature. Blending of aggregates of greater polish resistance with aggregates of this group will often improve pavement skid resistance. Aggregates in this group are suitable for all pavement courses other than the surface that is exposed to traffic.

The simulated traffic experimental program provided an evaluation of the skid resistance characteristics of three pavement types (portland cement concrete, asphaltic concrete, and seal coats) with several aggregate types. One of the initial concerns was the possibility that a pavement built with an aggregate selected for resistance to studded tire wear might polish under heavy conventional tire traffic. Consequently, the majority of the aggregates selected were considered to be highly resistant to wear.

The experimental program consisted of placing pavement sections in the AMOCO Oil Co. circular test track, located at Whiting, Ind., and exposing them to conventional tire traffic at approximately 75F with wet abrasives added and studded tire traffic at winter temperatures with wet abrasives and salt added. Twelve pavement sections were simultaneously subjected to simulated traffic up to 2,000,000 wheel passes. After exposure of 36 pavement sections in this manner, 12 of the sections were placed in the track and subjected to an additional 5,000,000 wheel passes with conventional tires. At periodic intervals, pavement skid resistance was measured with a British Portable Tester, wear with a Profilometer, and texture by the stereo-photo method.

Table 2 gives a brief description of the 36 pavement sections included in the experimental program. The specific aggregates used in the pavement sections, the location of the aggregate sources, and their classification by the groups developed during the study, are as follows:

| Aggregate Description and Source | Group |
|---|---|
| Crushed trap rock - Dresser, Wis. | III |
| Crushed graywacke - Richmond, Calif. | II |
| Crushed quarzite - Sioux Falls, S. Dak. | II |
| Expanded shale - Port Costa, Calif. | II |
| Chat (sand-size mine tailings) - Joplin, Mo. | III |
| Calcined bauxite (RASC grade) - Guyana | I |
| Crushed limestone - Annville, Pa. | V |

The laboratory test values for each aggregate are given in Table 3. The Texas Polish Value was determined in accordance with Texas test method Tex-438-A and is

TABLE 1 - COMPARATIVE PROTERTIES OF WEAR AND SKID-RESISTANT SYSTEMS FOR IMMEDIATE IMPLEMENTATION, USED AS REMEDIAL TREATMENTS

| PROPERTY | SYSTEM | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PCC, Optimum Design | Dense-Gr. AC, Opt. Design | Open-Graded AC | Skip-Graded AC | AC with precoated chips | Epoxy-modified AC | Asphalt Seal Coat | Rub. Asph. Seal Coat | Epo.-Asph Calc.-Baux. Seal | Sawed Long. Grooves |
| Applied cost range ($/sq. yard)[1,2] | NA | 0.75-1.50 | 0.50-1.20 | 1.00-1.75 | 2.00-2.50 | 6.75-11.25 | 0.20-0.30 | 0.50-0.75 | 6.00-10.00 | 0.50-1.00 |
| Estimated effective life (years)[2] | 5-15 | 5-15 | 5-10 | 5-15 | 10-15 | >10 | 2-5 | 2-7 | 7-13 | 4-7 |
| Relative wear factor[2,3] | 3 | 3 | 4 | 2 | 1 | 2 | 6 | 5 | 1 | 4 |
| Relative resistance to hydroplaning[4] | 4 | 4 | 1 | 4 | 3 | 4 | 2 | 2 | 2 | 2 |
| Estimated Skid Number range ($SN_{40}$-ASTM trailer)[2,4] | 50-65 | 50-65 | 55-65 | 50-65 | 55-70 | 55-65 | 50-65 | 50-60 | 65-80 | 40-50 |
| Relative skid speed gradient[5] | 3 | 3 | 1 | 3 | 2 | 3 | 2 | 2 | 1 | 3 |

[1]In terms of usual resurfacing thicknesses for plant-mixed and seal coat systems and of cost experience with grooving.

[2]Estimated assuming similar aggregates (except for the system where calcined-bauxite only is specified), with effective life varying with conditions such as traffic density, climate, etc.

[3]Wear in wheel track due to abrasive action of normal traffic (1== most resistant to wear).

[4]Ratings are on the basis of "1" being most desirable.

[5]Indicates fall-off of skid number with increasing speed (1 = least change).

# TABLE 2 - RUN NUMBER AND DESCRIPTION OF TEST SPECIMENS

| Specimen No. | Run No. | Description of Specimen |
|---|---|---|
| 01 | III | Portland cement concrete, normal cement factor, Dresser trap rock for both coarse and fine aggregate |
| 02 | III, IV | Same as No. 01 |
| 03 | III | Same as No. 01, except randomly spaced transverse grooves sawed in surface |
| 04 | III, IV | Same as No. 01, except higher cement factor |
| 05 | III | Same as No. 01, except fine aggregate is Joplin chat |
| 06 | III | Same as No. 01, except short steel fibers added |
| 07 | III, IV | Same as No. 01, except calcium aluminate cement used as binder |
| 08 | III | Same as No. 01, except emulsified epoxy added |
| 10 | I | Gussasphalt |
| 11 | I | Dense graded asphalt concrete, Dresser trap rock for both coarse and fine aggregate |
| 12 | II | Same as No. 11 |
| 13 | III, IV | Same as No. 11 |
| 14 | II | Same as No. 11, except rubberized in situ after compaction |
| 15 | I | Same as No. 11, except coarse aggregate is Quarry Products graywacke |
| 16 | I, IV | Same as No. 11, except coarse aggregate is Sioux Falls quartzite |
| 17 | II | Slurry seal with emulsified epoxy-asphalt binder, Dresser trap rock aggregate |
| 18 | II | Same as No. 17, except aggregate is Joplin chat |
| 19 | II | Seal coat, asphalt-extended polyurethane binder, calcined bauxite aggregate |
| 20 | II | Seal coat, special thermoplastic binder, Dresser trap rock aggregate |
| 21 | II, IV | Seal coat, epoxy-asphalt binder, Dresser trap rock aggregate |
| 22 | I, IV | Open-graded asphalt concrete, epoxy-asphalt binder, Dresser trap rock aggregate |
| 23 | I, IV | Same as No. 22, except Quarry Products graywacke aggregate |
| 24 | II | Same as No. 21 |
| 25 | I | Dense-graded asphalt concrete, epoxy-asphalt binder, Dresser trap rock for both coarse and fine aggregate, longitudinal grooves sawed in surface |
| 26 | II, IV | Gap-graded asphalt concrete, epoxy-asphalt binder, pre-coated chips rolled into surface while hot, Dresser trap rock for coarse and fine aggregate and for chips |
| 27 | II | Same as No. 21 and 24, except Quarry Products graywacke aggregate |
| 28 | II | Same as No. 21 and 24, except Sioux Fall quartzite aggregate |
| 29 | II, IV | Same as No. 21 and 24, except calcined bauxite aggregate |
| 30 | I | Gap-graded asphalt-concrete, pre-coated chips rolled into surface while hot, Dresser trap rock for coarse and fine aggregate, Quarry Products graywacke for chips |
| 31 | I | Same as No. 30, except Dresser trap rock for chips |
| 32 | I | Same as No. 31 |
| 33 | I | Same as No. 30, except Sioux Falls quartzite for chips |
| 34 | I | Same as No. 30, except Port Costa light-weight aggregate for chips |
| 35 | III, IV | Same as No. 01, except unsaturated monomer added to surface of cured and finished specimen |
| 36 | III, IV | Same as No. 11, except Annville limestone used for both coarse and fine aggregate |
| 37 | III | Same as No. 30, except Annville limestone used for coarse and fine aggregate and for chips |

Note: 09 was not used as a specimen number.

TABLE 3 - RESULTS OF TESTS ON AGGREGATES

| Aggregate | Texas Polish Value | L.A. Abrasion Loss, % | | Modified L.A. Abrasion | | California Durability | Washington Degradation |
|---|---|---|---|---|---|---|---|
| | | 100 rev. | 500 rev. | Loss % | Sediment ht., in. | | |
| Crushed trap rock | 33 | 2.5 | 9.9 | 9.1 | 7.4 | 87 | 93 |
| Crushed graywacke | 46 | 4 | 20 | 18.8 | 13.9 | 70 | 67 |
| Crushed quartzite | 34 | 4.5 | 19.4 | 15.9 | 8.9 | 96 | 96 |
| Expanded shale | 50 | 6.6 | 24.8 | --- | --- | 96 | 87 |
| Calcined bauxite | 44 | --- | --- | --- | --- | 100 | 96 |
| Crushed limestone | 22 | --- | 16.6 | 14.6 | 8.6 | 90 | 84 |
| Typical requirements: | 35 min. | 10 max. | 40 max. | 40 max. | 13 max. | 35 min. | 25 min. |

similar to the British PSV test. Examples of data included in the report are given in Tables 4 and 5, and in Figures 1 and 2.

All skid resistance measurements were made with the British Portable Tester and values reported as BPN. Although this laboratory procedure operates at slow speed in relation to a skid trailer and is influenced in an inconsistent manner by pavement surface texture, the data are considered to be a reasonable evaluation of the pavement sections in a relative sense. Each data point is an average of readings from four small areas of the pavement section being tested. BPN values are generally larger than SN40 skid trailer values for the same pavement sections.

It was generally found that all pavement sections had high initial skid resistance values. The trend was for the skid resistance to drop very rapidly during the first 50,000 wheel passes, continue to reduce at a moderate rate through 1,000,000 wheel passes, and then continue to reduce at a slow rate through the 7,000,000 wheel passes. During this particular test program there did not appear to be a terminal polish level.

From a relative standpoint, the asphalt mix-type pavement with limestone coarse aggregate polished at a faster rate and reached a lower level of skid resistance than similar pavements with trap rock, graywacke, and quartzite aggregates. This is consistent with field experience and the Texas Polish Value (TPV) for these aggregates. Although not in quantitative agreement with the differences in TPV, the asphalt mix pavements using graywacke coarse aggregates tended to be more polish-resistant than those using trap rock and quartzite.

Another interesting observation is that the stereo-photo method appears to provide a more consistent and realistic evaluation of skid resistance than the BPN method. For some unexplained reason, most of the BPN values at 4,000,000 and 5,000,000 wheel passes were higher than at traffic on either side of these points. The stereo-photo estimated SN values do not show this inconsistency. Also, the BPN values for dense-

# TABLE 4 - SUMMARY OF CORRECTED BPN, NON-STUDDED TIRES

| Specimen Number | Initial | Number of Wheel Passes | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 50,000 | 500,000 | 1,000,000 | 2,000,000 | 3,500,000 | 4,000,000 | 5,000,000 | 6,000,000 | 6,500,000 | 6,700,000 | 7,000,000 |
| **PCC Types** | | | | | | | | | | | | |
| 01 | 73 | 69 | 76 | 57 | 59 | | | | | | | |
| 02 | 73 | 68 | 65 | 61 | 62 | 54 | 58 | 58 | 49 | 42 | 50 | 46 |
| 03 | 83 | 61 | 51 | 56 | 52 | | | | | | | |
| 04 | 58 | 79 | 69 | 57 | 67 | 56 | 66 | 60 | 51 | 53 | 54 | 53 |
| 05 | 80 | 74 | 74 | 63 | 71 | | | | | | | |
| 06 | 71 | 61 | 63 | 51 | 62 | | | | | | | |
| 07 | 75 | 69 | 59 | 58 | 59 | 61 | 61 | 58 | 49 | 47 | 49 | 47 |
| 08 | 76 | 73 | 53 | 48 | 57 | | | | | | | |
| 35 | 63 | 48 | 45 | 46 | 45 | 48 | 55 | 56 | 51 | 48 | 52 | 47 |
| Range | 58-83 | 48-79 | 45-76 | 46-63 | 45-71 | 48-61 | 55-66 | 56-60 | 49-51 | 42-53 | 49-54 | 46-53 |
| Average | 72 | 67 | 62 | 55 | 59 | 55 | 60 | 58 | 50 | 48 | 51 | 48 |
| **Asphalt Mix Types** | | | | | | | | | | | | |
| 11 | 72 | 57 | 52 | 46 | 45 | | | | | | | |
| 12 | 78 | 63 | 58 | 59 | 59 | | | | | | | |
| 13 | 71 | 59 | 50 | 49 | 47 | 49 | 54 | 53 | 42 | 42 | 42 | 39 |
| 14 | 81 | 67 | 58 | 61 | 53 | | | | | | | |
| 15 | 68 | 64 | 56 | 49 | 51 | | | | | | | |
| 16 | 69 | 57 | 56 | 49 | 49 | 49 | 54 | 51 | 44 | 46 | 48 | 44 |
| 22 | 59 | 53 | 54 | 47 | 49 | 47 | 53 | 48 | 45 | 45 | 44 | 43 |
| 23 | 61 | 54 | 55 | 49 | 50 | 54 | 60 | 58 | 49 | 51 | 51 | 47 |
| 25 | 82 | 55 | 53 | 49 | 48 | | | | | | | |
| 26 | 71 | 69 | 64 | 59 | 46 | 42 | 53 | 55 | 37 | 39 | 43 | 49 |
| 30 | 68 | 64 | 59 | 49 | 51 | | | | | | | |
| 31 | 61 | 55 | 53 | 44 | 46 | | | | | | | |
| 32 | 72 | 53 | 50 | 43 | 44 | | | | | | | |
| 33 | 75 | 57 | 54 | 50 | 45 | | | | | | | |
| 34 | 79 | 73 | 62 | 55 | 55 | | | | | | | |
| 37 | 64 | 48 | 47 | 42 | 43 | | | | | | | |
| 10 | 73 | 64 | 60 | 54 | 55 | | | | | | | |
| 36 | 72 | 46 | 45 | 44 | 42 | 46 | 48 | 46 | 37 | 37 | 35 | 36 |
| Range | 59-82 | 46-73 | 45-64 | 42-61 | 42-59 | 42-54 | 48-60 | 46-58 | 37-49 | 37-51 | 35-51 | 36-49 |
| Average | 71 | 59 | 55 | 50 | 49 | 48 | 54 | 52 | 42 | 43 | 44 | 43 |
| **Seal Types** | | | | | | | | | | | | |
| 17 | 82 | 84 | -- | -- | -- | | | | | | | |
| 18 | 79 | 72 | -- | -- | -- | | | | | | | |
| 19 | 82 | 90 | 85 | -- | -- | | | | | | | |
| 20 | 79 | 77 | -- | -- | -- | | | | | | | |
| 21 | 88 | 75 | 65 | 65 | 68 | 55 | 52 | 51 | 47 | 48 | 47 | 44 |
| 24 | 89 | 77 | 62 | 71 | 67 | | | | | | | |
| 27 | 87 | 81 | 66 | 67 | 68 | | | | | | | |
| 28 | 84 | 75 | 67 | 64 | 71 | | | | | | | |
| 29 | 90 | 90 | 78 | 76 | 78 | 69 | 72 | 71 | 59 | 62 | 64 | 57 |
| Range | 79-90 | 72-90 | 62-85 | 64-76 | 67-78 | 55-69 | 52-72 | 51-71 | 47-59 | 48-62 | 47-64 | 44-57 |
| Average | 84 | 80 | 71 | 69 | 70 | 62 | 62 | 61 | 53 | 55 | 56 | 51 |
| **Overall:** | | | | | | | | | | | | |
| Range | 58-90 | 46-90 | 45-85 | 42-76 | 42-78 | 42-69 | 48-72 | 46-71 | 37-59 | 37-62 | 35-64 | 36-57 |
| Average | 75 | 66 | 60 | 54 | 55 | 53 | 57 | 55 | 47 | 47 | 48 | 46 |

TABLE 5 - COMPARISON OF CORRECTED BPN WITH ESTIMATE OF SN AT 30 AND 60 MPH BY STEREO PHOTO METHOD, NON-STUDDED TIRE RUNS

| | | 50,000 Wheel Passes | | | 2,000,000 Wheel Passes | | | 5,000,000 Wheel Passes | | | 7,000,000 Wheel Passes | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Specimen Number | BPN | Stereo Photo 30 | Stereo Photo 60 | BPN | Stereo Photo 30 | Stereo Photo 60 | BPN | Stereo Photo 30 | Stereo Photo 60 | BPN | Stereo Photo 30 | Stereo Photo 60 |
| PCC Types | 01 | 69 | 87 | 80 | 59 | 68 | 57 | | | | | | |
| | 02 | 68 | 83 | 76 | 62 | 73 | 68 | 58 | 55 | 53 | 46 | 42 | 39 |
| | 03 | 61 | 71 | 63 | 52 | 58 | 49 | | | | | | |
| | 04 | 79 | 88 | 77 | 67 | 68 | 56 | 60 | 57 | 46 | 53 | 56 | 45 |
| | 05 | 74 | 81 | 74 | 71 | 63 | 58 | | | | | | |
| | 06 | 61 | 81 | 73 | 62 | 63 | 53 | | | | | | |
| | 07 | 69 | 73 | 63 | 59 | -- | -- | 58 | 44 | 38 | 47 | 41 | 33 |
| | 08 | 73 | 73 | 66 | 57 | 64 | 57 | | | | | | |
| | 35 | 48 | 56 | 51 | 45 | 53 | 40 | 56 | 53 | 40 | 47 | 53 | 40 |
| | Range | 48-79 | 56-88 | 51-80 | 45-71 | 53-73 | 40-68 | 56-60 | 44-57 | 38-53 | 46-53 | 41-56 | 33-45 |
| | Average | 67 | 77 | 69 | 59 | 64 | 55 | 58 | 52 | 44 | 48 | 48 | 39 |
| Asphalt Mix Types | 11 | 57 | 72 | 66 | 45 | 72 | 57 | | | | | | |
| | 12 | 63 | 76 | 66 | 59 | 50 | 32 | | | | | | |
| | 13 | 59 | 74 | 66 | 47 | 66 | 57 | 53 | 54 | 43 | 39 | 45 | 37 |
| | 14 | 67 | 73 | 65 | 53 | 53 | 46 | | | | | | |
| | 15 | 64 | 72 | 67 | 51 | 72 | 60 | | | | | | |
| | 16 | 57 | 68 | 63 | 49 | 65 | 59 | 51 | 59 | 46 | 44 | 56 | 43 |
| | 22 | 53 | 67 | 61 | 49 | 65 | 56 | 48 | 64 | 52 | 43 | 64 | 51 |
| | 23 | 54 | 67 | 56 | 50 | 66 | 55 | 58 | 64 | 52 | 47 | 64 | 51 |
| | 25 | 55 | 68 | 64 | 48 | 68 | 62 | | | | | | |
| | 26 | 69 | 79 | 72 | 46 | 61 | 54 | 55 | 54 | 47 | 49 | 52 | 44 |
| | 30 | 64 | 81 | 75 | 51 | 81 | 71 | | | | | | |
| | 31 | 55 | 68 | 64 | 46 | 69 | 62 | | | | | | |
| | 32 | 53 | 55 | 51 | 44 | 55 | 49 | | | | | | |
| | 33 | 57 | 67 | 63 | 45 | 46 | 44 | | | | | | |
| | 34 | 73 | 54 | 48 | 55 | 39 | 36 | | | | | | |
| | 37 | 48 | 46 | 42 | 43 | -- | -- | | | | | | |
| | 10 | 64 | 64 | 59 | 55 | 64 | 55 | | | | | | |
| | 36 | 46 | 67 | 63 | 42 | -- | -- | 46 | 46 | 41 | 36 | 40 | 34 |
| | Range | 46-73 | 46-81 | 42-75 | 42-59 | 39-81 | 32-71 | 46-58 | 46-64 | 41-52 | 36-49 | 40-64 | 34-51 |
| | Average | 59 | 68 | 62 | 49 | 62 | 53 | 52 | 57 | 47 | 43 | 54 | 43 |
| Seal Types | 17 | 84 | 66 | 63 | -- | 41 | 32 | | | | | | |
| | 18 | 72 | 78 | 63 | -- | -- | -- | | | | | | |
| | 19 | 90 | 75 | 69 | -- | -- | -- | | | | | | |
| | 20 | 77 | 77 | 63 | -- | -- | -- | | | | | | |
| | 21 | 75 | 84 | 78 | 68 | 58 | 53 | 51 | 44 | 37 | 44 | 41 | 33 |
| | 24 | 77 | 75 | 61 | 67 | 59 | 47 | | | | | | |
| | 27 | 81 | 83 | 69 | 68 | 59 | 47 | | | | | | |
| | 28 | 75 | 85 | 79 | 71 | 67 | 56 | | | | | | |
| | 29 | 90 | 86 | 72 | 78 | 72 | 62 | 71 | 66 | 58 | 57 | 63 | 54 |
| | Range | 72-90 | 66-86 | 61-79 | 67-78 | 41-72 | 32-62 | 51-71 | 44-66 | 37-58 | 44-57 | 41-63 | 33-54 |
| | Average | 80 | 79 | 69 | 70 | 59(63)* | 50(53)* | 61 | 55 | 48 | 51 | 52 | 44 |
| Overall: | Range | 46-90 | 46-88 | 42-80 | 42-78 | 39-81 | 32-71 | 46-71 | 44-66 | 37-58 | 36-57 | 40-64 | 33-54 |
| | Average | 66 | 73 | 65 | 55 | 62 | 53 | 55 | 55 | 46 | 46 | 51 | 42 |

*5 only.

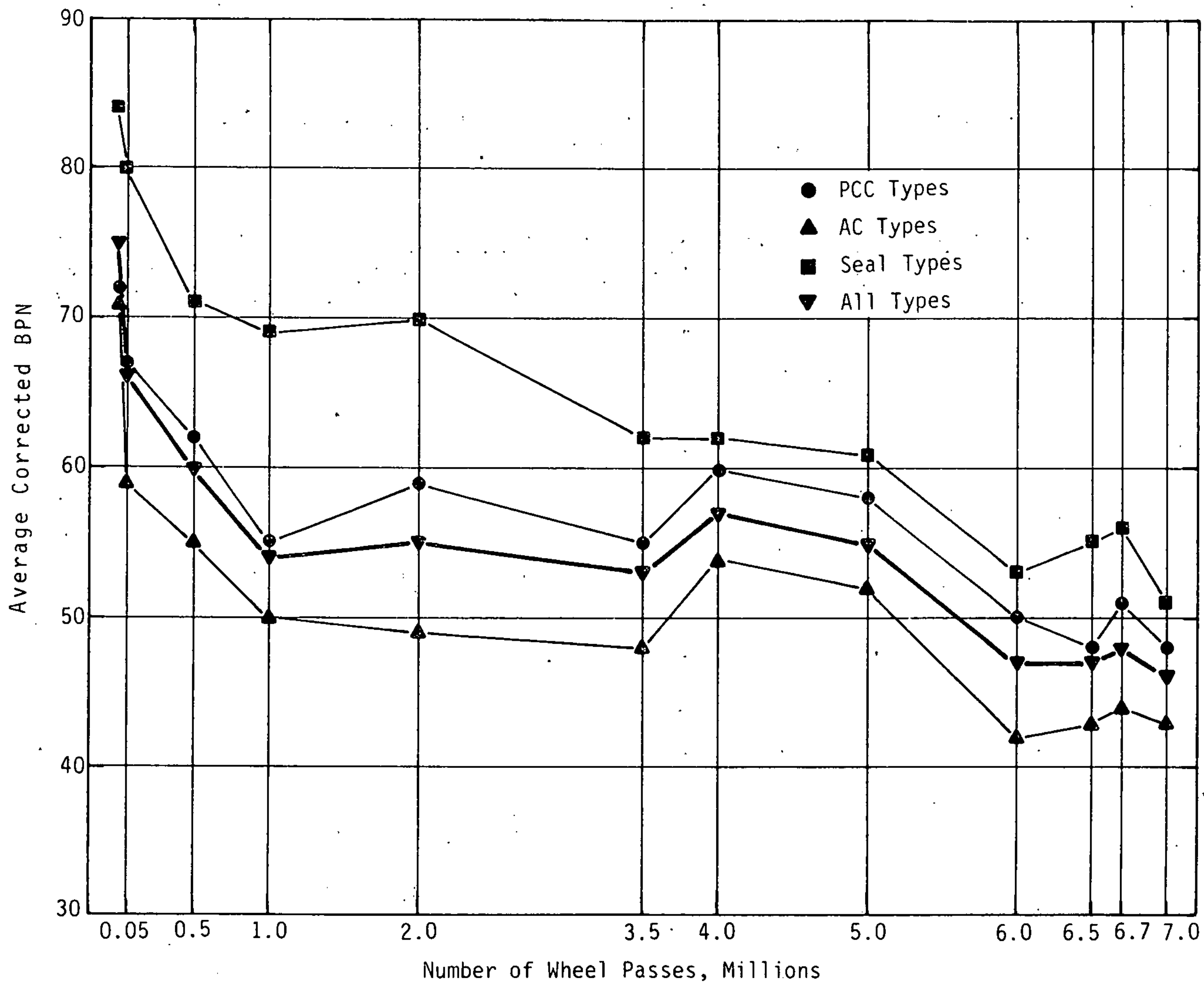


FIGURE 1 - AVERAGE CORRECTED BPN, BY PAVEMENT TYPES, NON-STUDDED TIRE RUNS

graded asphaltic concrete were similar but the stereo-photo estimated SN values for the same pavement sections showed the open-graded pavements to have higher skid resistance than the dense-graded pavements.

The experimental program adds substantially to the quantitative data on pavement skid resistance and generally confirms previous research and experience. The findings are summarized as follows:

1. Conventional portland cement and asphalt pavements perform quite satisfactorily as skid-resistant surfaces under all but the most severe traffic conditions when attention is given to aggregate selection, mix design, and surface texture.

2. Seal-coat-type surfaces provide high initial skid resistance and are economical; but when conventional binders are used satisfactory performance is limited to light to moderate traffic volumes. Seal coats using epoxy-asphalt binders and polish-resistant aggregates are suitable for higher traffic volumes.

3. The polish resistance and retention of texture of portland cement concrete pavements is improved by increasing the cement factor to 6 sacks per cubic yard and using sharp, polish-resistant fine aggregate.

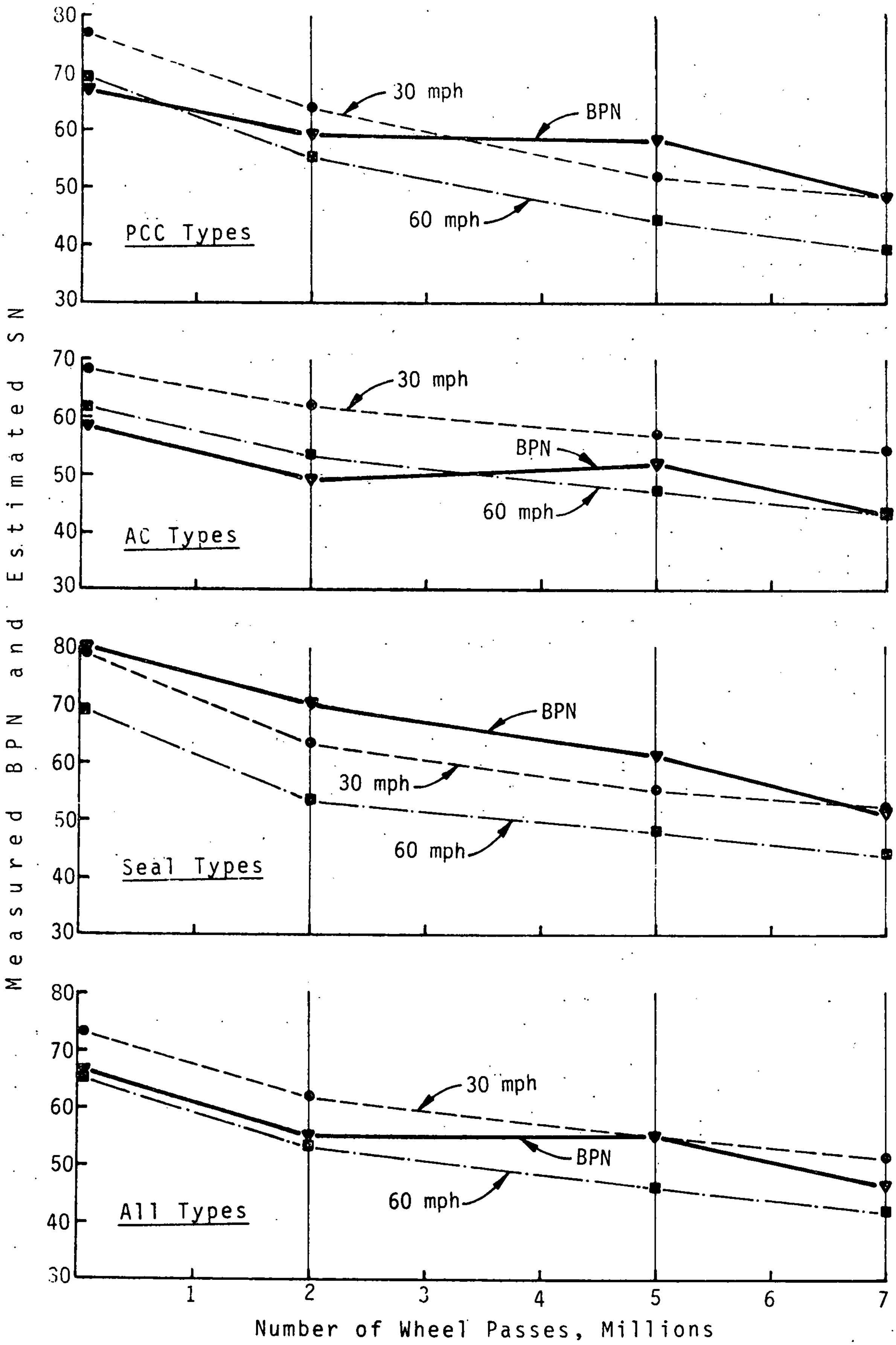


FIGURE 2 - AVERAGE OF MEASURED BPN COMPARED TO ESTIMATE OF SN AT 30 AND 60 MPH BY STEREO PHOTO INTERPRETATION

4. The polish resistance of asphaltic concrete pavements is influenced primarily by the characteristics of the coarse aggregate.

5. An open-graded asphaltic concrete using an epoxy-asphalt binder and polish-resistant aggregate appears to have outstanding skid-resistant and anti-hydroplaning characteristics. Due to the cost of about $10 per square yard, use will undoubtedly be limited to specialized situations such as high traffic volume urban expressways in areas of moderate to heavy rainfall.

6. Use of innovative additives and binders such as steel fibers, emulsified epoxy, in-situ rubberization, calcium aluminate cement, and unsaturated monomer did not appear to improve wear or skid resistance of the pavements tested.

## APPLICATIONS

The results of this research are reported in terms that are clear and understandable to the practicing engineer. The guidelines for design and construction of skid-resistant pavement surfaces are flexible and adaptable to individual highway agency situations and are thus suitable for immediate implementation; they do not require additional research in order to be useful. Furthermore, their development has been based on substantial field experience and confirmed through a simulated traffic experimental study. The experimental study itself is judged to be realistic because of the correlation between the British Portable Tester Values (BPN) and the SN values estimated by the stereo-photo method that has been correlated with locked-wheel skid trailer data by other studies. Over-all, therefore, it is judged that use of the guidelines will result in improved practice.

More precise evaluation of the relationship between the performance of the pavements in the test track and similar pavements exposed to actual traffic and environmental conditions is certainly desirable. This will involve design and construction of the similar pavements and periodic collection of skid resistance data using both a British Portable Tester and a locked-wheel skid trailer. Given the present state of the art, research of this type could be conducted by individual highway agencies.

**TRANSPORTATION RESEARCH BOARD**
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418