

Research Report  
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**SKID RESISTANCE OF PAVEMENTS**

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## ABSTRACT

Standard pavement types and experimental surfaces on roads throughout Kentucky were evaluated in terms of skid resistance and effects of traffic, wear, and polishing. Friction-vs-speed gradients and the relationships between locked-wheel and incipient friction were determined. Asphaltic concrete pavements on high-speed, four-lane roads were found to be significantly more skid resistant than on two-lane highways and somewhat more skid resistant than concrete surfaces (especially those containing calcareous gravel aggregates). Sand-asphalt surfaces containing significant proportions of limestone sands showed inadequate level of friction for the traffic sustained. Several experimental sand asphalts without limestone sands exhibited greater skid resistance; Kentucky rock asphalt surfaces remain the most skid resistant of all surfaces investigated.

**KEY WORDS:** Skid resistance, peak slip resistance, friction, pavements, aggregates, surface texture, slipperiness, polishing, wear

## INTRODUCTION

Traffic polishes all pavements; all pavements wear and weather. The development of slipperiness and loss of friction (traction) is closely associated with cumulative traffic. The loss of traction is most severe during the first few years. After five or six million vehicle passes, the friction value tends to stabilize. Judgments of performance of pavements are based on mature values. Some types or surface treatments, however, may exhibit low skid resistance earlier. The paper presents performance histories and analyses of standard and experimental surfaces in Kentucky.

No single mode of testing, such as locked wheel sliding or peak friction at critical percent slip (8 to 20 percent), completely describes the traction available to a vehicle. Kentucky trailer measurements (1) provided both locked-wheel skid resistance, expressed as Skid Numbers, SN, and peak slip resistance, expressed as Peak Slip Number, PSN. Skid resistance of pavements decreases as speed increases; material textural differences amongst pavements result in differing friction-vs-speed relationships. Measurement at a single test speed does not fully characterize a surface. The ASTM E-274-70 (2) standard test speed is 40 mph; at least three test speeds are needed for research purposes. By choice, tests were made at 20, 40, and 60 mph. Where the speed limit was 70 mph, this higher test speed was used. The peak slip resistance at these speeds may be a better indicator of traction available to vehicles during acceleration, deceleration, and perhaps in cornering and passing maneuvers. However, in panic braking where the driver locks wheels and skids, the Skid Number more closely reflects available traction, and it may be useful in ascertaining stopping distances or speed reduction prior to collision. Obviously, overall evaluation of pavement is not a simple task.

## ASPHALTIC CONCRETE

Limestone remains the predominant coarse aggregate in surface courses. Most, if not all, limestones are susceptible to rapid polishing. Surface courses contain limestone coarse aggregate and natural or conglomerate sand in the proportion of not less than 40 percent of the combined aggregate. Mineral composition, gradation and particle-shape requirements for sand, however, were not specified.

In-service performance of asphaltic concrete surfaces on US and KY routes is shown in Figure 1. Only 40-mph test data are shown. The cumulative traffic per lane was calculated from ADT data. No weighting factors for trucks as opposed to automobiles were considered.

Scatter of data, on the basis of available information, could not be explained. Percentages of various aggregates and asphalt contents bore no relationship to deviations from the regression curve. Practically all of the surfaces contained the following:

Intermediate Grade Limestone (No. 9 or No. 8)	40%
Limestone Filler	20%
Natural, Siliceous Sand	40%
Asphalt Content	5.3% -- 5.6%

A few surfaces varied in relative proportions of the two limestones, but all contained at least 40 percent natural (river or pit) sand. These sands usually contained a large percentage of well-rounded particles.

Performance of asphaltic concrete surfaces on

interstate and parkway (expressway) roads is shown in Figure 2. At 70 mph, and for the same cumulative traffic, lower values were found in the outer lanes. Traffic density appears to be the affecting factor. A limited number of these projects was tested at 40 mph to obtain a relationship between the two test speeds. An equivalent  $SN_{40}$  curve, derived from the correlation given in Figure 3, is also shown in Figures 1 and 2. Surprisingly, the  $SN_{40}$  values interpolated from Figure 3 failed to match the  $SN_{40}$  values measured on two-lane roads. These differences are shown in Figure 1. No single explanation for the difference may be offered. Even though all the paving projects were constructed under the same general surface mix specifications; hardness and wear characteristics of limestone and (or) sand aggregates from different sources most likely affected the skid resistance to some extent. Traffic on interstate and parkway projects was quite limited for some time after construction. In contrast, traffic on projects involving other routes was permitted soon after paving. Also, differences in traffic characteristics; i.e. speed, composition, channelization, maneuvers, etc.; and roadway geometrics affected wear and polishing. Inaccuracy of ADT information, environmental factors, and variables associated with the test, of course, may obscure the precise influence of traffic.

Changes in friction with test speed are shown in Figure 4. The slopes of the lines are referred to as the speed gradient,  $G$ , expressed as change in SN per velocity increment. The smaller the  $G$  value, the less the reduction in skid resistance with increasing speed. In the increment between 40 mph and 60 mph, the average  $G$  was approximately 0.4, a loss of about 8 Skid Numbers.

Peak Slip Number has been defined previously. Figure 5 shows the measured SN and its corresponding PSN for three test speeds. Separate regression line were required for each speed. The correlation between these values was rather good, but the data shows considerable scatter as reflected by the standard error of estimate ( $E_s$ ). Figure 6 was constructed from the regression equations. Friction values were converted to  $PSN/SN$ , and equal-SN curves were drawn. This graph clearly demonstrates a proportionally higher PSN associated with the lower SN values. Moreover, for a given SN value, the PSN increased with speed. The full significance of this finding is not understood. It appears that a percentage of slip is equivalent to a percentage reduction in speed in the skid mode. For instance, 12 percent slip at 60 mph is equivalent to about 7 mph in the skid mode and 53 mph free running. These may be viewed as vector components of the velocity. Extrapolating the speed-gradient curves (Figure 4) to 7 mph yields a value of, let us say, 70 Skid Numbers.

In the case chosen, the  $SN_{60}$  was 40. Now, proceeding to Figure 5, and entering the graph with an  $SN_{60}$  of 40, 70 is found to be within the limits of the PSN correlation data. Taking the highest case from Figure 4 ( $SN_{60} = 55$ ), extrapolation to 7 mph yields a PSN value of 87. For the lowest in Figure 4 ( $SN_{60} = 25$ ), extrapolation to 7 mph yields a SN of 51; Figure 5 also yields these values, approximately, for the PSN.

If, indeed, the above interpretations are correct, advantages of the limited-slip method of braking would be predictable from speed gradients and percent slip at which peak traction occurs. Presumably, a limited-slip braking system would shorten the stopping distance.

### KENTUCKY ROCK ASPHALT

Eleven paving projects were constructed in 1966 and 1967 and monitored for skid resistance. Performance of these surfaces is shown in Figure 7. Reduction in skid resistance with cumulative traffic is apparent. The surfaces are smooth but rather porous (about 12 percent voids). The relationship between skid resistance and speed is shown in Figure 8. The speed gradient is approximately 0.6 (40 mph to 60 mph). Figure 9 shows the SN data and corresponding PSN's. There was no increase in  $PSN/SN$  (Figure 6) as the speed increased. However, Figure 9 indicates that the loss of traction in the slip mode is almost uniquely constant, regardless of speed. This may mean that no hydraulic influences (hydroplaning) are present.

### PORTLAND CEMENT CONCRETE

Limestone was used as coarse aggregate in most concrete pavements. Projects on I 75 in the northern Kentucky area and projects on I 71, however, contained crushed, calcareous, glacial gravel. Fine aggregates were natural sand, comprising 34 to 40 percent of combined solid volume of the fine and coarse aggregate.

In 1970, the latest available data were used to prepare Figure 10. All but one were on interstate and parkway roads. Most were tested in 1970, but some were tested in 1969. The ADT's on some segments were quite high. In some instances both inner and outer lanes were tested. Measurements in the inner lanes did not deviate from performance trends of the outer lanes. Pavements containing gravel coarse aggregate were found to be less skid resistant at 40 mph than those containing limestone aggregate.

In 1971, the entire interstate and parkway systems were tested at 70 mph, and these results are presented in Figure 11. Several sections were also tested at 40 mph to obtain a relationship between the two speeds. These data were included in Figure 3. An equivalent SN<sub>40</sub>-curve is shown in Figure 11. The 70-mph performance of pavements on I 75 containing crushed gravel appeared to be comparable to other sections containing limestone. However, the northernmost projects had posted speed limits of 50 mph and 60 mph and, therefore, perhaps greater weight should be given to the 40-mph curve shown in Figure 10. The I 71 concrete pavements, all constructed with calcareous glacial gravel, exhibited low skid resistance very early. Several sections of the highway should be considered slippery when wet. Visual inspection of the surfaces revealed a predominance of well-rounded and polished gravel particles exposed and protruding above the matrix.

Speed gradients for several concrete pavements are shown in Figure 12. The surfaces exhibited similar textural characteristics, and the average G was approximately 0.5. The relationships between PSN and SN are shown in Figure 13. The equal-SN curve in Figure 6 shows a peculiar hump at a test speed of 40 mph and may be due to scatter and the limited data available for analysis.

### SAND ASPHALT

Between 1964 and 1970, several sand asphalt surfaces were constructed. Only rural sections of these roads were monitored. A plot of skid resistance versus cumulative traffic is presented in Figure 14. Because of the scatter of data and the limited number of projects involved, a meaningful best-fit curve could not be obtained. Chemical composition and shape of the sands used varied considerably amongst these projects. Limestone sands, especially in the larger sand size, surely diminished skid resistance. A pavement in Boone County on KY 236 has performed well after 11 million vehicle passes. The mix contained only 13 percent limestone sand. Most surfaces did not exhibit the desired level of friction for the volume of traffic sustained. Consequently, this style of sand asphalt was discontinued.

Change in skid resistance with speed ( $G = 0.6$ ) is shown in Figure 15. The relationship between the two friction measurements (Figure 16) was pronouncedly speed dependent. The PSN/SN ratio significantly increased with speed (refer to Figure 6); this might be regarded as a positive attribute of the surfaces.

### EXPERIMENTAL SAND-ASPHALT PROJECTS

Because of the apparent failure to obtain desired friction level with sand asphalts composed of not less than 50 percent quartz ( $\text{SiO}_2$ ), five experimental surfaces were constructed on US 27 in Pulaski County. The 1.5-mile sections were tested with an automobile soon after construction. Precise conversion of friction measurements then employed and the subsequent trailer tests was not possible. Therefore, performance of the surfaces since 1968, as shown in Figure 17, was based on the trailer data.

A single experimental surface, designed in accordance with a given specification and constructed with particular aggregate type available locally, introduces uncertainties as to how representative the pavement may be of a similarly designed mix placed elsewhere. Also, several other problems hindered proper evaluation of the surfaces in Pulaski County. Sections 4 and 5B were located on a rural segment of US 27 having a lower ADT than the other sections located in more congested areas near Somerset. Limestone aggregate used later to the shoulders adjoining the experimental sections was scattered onto the pavement and became imbedded. The percentages of the surfaces composed of extraneous aggregate were:

SECTION	PERCENT OF AREA
1 Regular Sand Asphalt	1
2B Open-Graded High Silica	16-SB, 27-NB
3 Open-Graded Medium Silica	2
4 Kentucky Rock Asphalt	3
5B Simulated Kentucky Rock Asphalt	2

Skid resistance of the sections was surely affected, particularly Section 2B. The extent of the decrease in terms of SN, however, cannot be accurately determined. Since the primary concern was in comparing the sections with each other, only the loss of friction on 2B need be considered. Simplified assumptions concerning the surface yielded an approximate difference of 3 Skid Numbers. Therefore, the skid resistance of this surface should be increased about 3 Skid Numbers.

No reduction in friction was noted on any of the sections in the three-year period of monitoring. Large variations in SN shown in Figure 17 were partly due to temperature differences encountered on the various test dates. The major variations, however, were associated with seasonal changes; SN values were lowest during the fall and highest in the late winter and spring periods.

The latest measurements (August 1971) (three test speeds) are presented in Figure 18. The pavements ranked in the order anticipated. Regular sand asphalt exhibited the lowest friction and Kentucky rock asphalt the highest. Both surfaces seemed to be rather comparable to similar pavements constructed elsewhere. As expected, the open-graded, high-silica pavement yielded higher skid resistance than the open-graded, medium-silica section. Simulated Kentucky rock asphalt did not prove to be comparable to the Kentucky rock asphalt.

Only a slight difference in friction was found between the open-graded, medium-silica and the regular sand asphalt, containing 33 percent and 36 percent limestone sand, respectively. Limestone sand obviously reduces the skid resistance of sand asphalts. The frictional level achieved on Sections 2B and 5B, however, must be viewed with some disappointment. Test values at 60 mph were very low. Surfaces of this type are not suitable for deslicking purposes on roadways carrying high-speed traffic.

## DISCUSSION

The skid trailer has enabled extensive testing in the locked-wheel mode and in the incipient-skid mode. But, more importantly, tests have been made at speeds much greater than those considered to be safe with the automobile method of testing. The interstate and parkway (expressway) systems, therefore, were tested at 70 mph; some selected projects were also tested at 40 mph. The regression curves in Figure 19 permit summary comparison of in-service performance of asphaltic concrete and PCC surfaces on interstate and parkway routes. PCC pavements are now showing about 4 Skid Numbers lower skid resistance than the asphaltic concrete at 70 mph. These differences in performance have not been apparent previously. Wear induced by studded tires and seasonal polishing are believed to be significant influences. Obviously, corrective measures will be required to improve some sections of interstate roads before they have fulfilled their 20-year design life. Roadway curves may be remedied by overlays, grooving, etching, etc. Continuous grooving or texturing has not been found to be economically feasible.

Texturing of freshly placed concrete surfaces has been recognized to be important. The added macrotexture or macroroughness improves tire-pavement friction and reduces the potential for hydroplaning. The texture depth (amplitude), spacing (pitch) between adjoining ridges, wear rates, and direction of texturing are important considerations in choosing a method or style.

Skid resistance on most pavements has been adequate for the first few million vehicle passes. Broomed finishes improve initial friction level and reduce hydroplaning; however, resulting tire noise in objectionable. A fluted roller or float method of texturing (3) holds promise. Such devices could be designed to construct evenly spaced grooves (3/8 inch to 1/2 inch centers) having uniform and significant (1/8 inch) amplitudes. Undoubtedly the rate of wear would be increased but the greater depth would be somewhat compensating. The net effect on long-term frictional level is believed to be positive. Regardless of the method employed, the direction of texturing should be transversely across the pavement.

Of the surface types monitored on rural US and KY highways, Kentucky rock asphalts exhibited the highest skid resistance. Sand asphalts have not provided the desired level of friction primarily due to the limestone sands in the aggregate (see Figure 20).

The need for thin-layered asphaltic surface courses (approximately 1/2 inch) remains, and the demand for them will grow, particularly as concrete pavements require deslicking. Such surfaces, in contrast to the asphaltic concrete surface courses, must meet the following criteria: 1) superior skid resistance, especially at the higher traffic speeds, 2) wear rates commensurate with the desired service life, and 3) competitive cost per square yard of material. However, conditions may warrant higher expenditures to achieve desired friction levels.

The demand for skid testing has exceeded the capabilities of a single tester. Testing schedules, therefore, were adjusted to high priority needs and thus limited the frequency and extent to which a given section could be tested. Multi-speed testing was kept to a minimum. Tests at 40 mph are standard according to ASTM E-274-70 and are made routinely for comparative purposes. However, selected surfaces were tested at other speeds. In summary, Figure 21 was prepared to show representative curves for each pavement type by choosing a common SN value of 40 at 40 mph. The Kentucky rock asphalts were much higher in friction and were not directly comparable.

Only limited experimental efforts were devoted to the peak friction measurements; and, therefore, much remains to be learned. Proportionately higher PSN were obtained on the lower SN surfaces, as shown in Figure 22. The PSN/SN ratio for several pavement types increased with speed; this indicates that the peak friction did not decrease with speed as much as the locked-wheel friction. These trends must be viewed as positive attributes towards safer driving in wet conditions. In fact, performing driving tasks and maneuvers would be further restricted and more hazardous if it were not so.

Introduction and use of studded tires in recent years, especially on vehicles from the northern states which travel the interstate roads in Kentucky, has contributed to increased rate of pavement wear. Damage to concrete pavements must be viewed with particular concern. Because the traffic stream is rather channelized, pavement wear on all surface types occurs primarily in the wheel paths and in time develops measurable rut depth. Rutting in bituminous pavements is caused partly by wear and partly by heavy loads. During rainfall, rutted wheel tracks tend to accumulate water and further increase driving hazards associated with spray and hydroplaning. Effectiveness of the studded tire as a safety innovation has not been demonstrated (4). Because of limited benefits and the seldomness of icy conditions and because of the damage done otherwise, studded tires should be discouraged and perhaps outlawed as several states and Canadian provinces have already done.

Slipperiness of pavements remains a problem. Success in the development of improved deslicking materials and surfacing courses will in time upgrade skid resistance of roadways and thereby reduce accidents attributable to pavement slipperiness.

Figure 23 shows the approximate stopping distances on dry and wet pavements. The stopping distance on wet pavement is based on the average skid resistance (trailer) of some 430 projects. The median Skid Number for these projects at 40 mph test speed was 40. Test data at other speeds were used to determine a representative SN versus speed relationships. The equivalent stopping distance was calculated largely on the basis of previous correlations between automobile stopping distances and trailer measurements. Curves shown for wet pavements (approximately 0.02 inch water depth), of course, demonstrate the distances an automobile, equipped with ASTM test tires, may skid in an emergency situation. Increased water thickness on the pavement and tires in poor condition (tread depth of 1/8 inch or less) would contribute to increasing stopping distances of automobiles, while automobiles equipped with good quality commercial tires (5) with significant tread depth would result in somewhat shorter distances on pavements characterized in Figure 23. Obviously, driving speeds on wet pavements would have to be reduced significantly in order to achieve the same level of safety (in terms of stopping distances) provided by dry conditions. For instance, where the speed limit is 70 mph, the dry stopping distance is 205 feet; wet-weather speed must be reduced to approximately 50 mph (for a median SN project) to be able to stop in the same distance.

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Public awareness of wet-pavement conditions has not been materially manifested in driver behavior. Most drivers choose to retain speeds near the legal limits regardless of weather and road conditions. This practice should be discouraged. Driver education through the broadcast media and by other means should, of course, be encouraged. Legal restraints on driving speeds remain a reasonable but untried alternative at this time. To safeguard the public from undue hazards associated with high-speed driving on wet pavements, the following speed limits are suggested:

POSTED SPEED LIMIT	SUGGESTED SPEED LIMITS WHEN WET
70	50
60	45
50	40

### SUMMARY AND CONCLUSIONS

Asphaltic concrete was found to be significantly more skid resistant on interstates and parkways (expressways) than on two-lane roads although the same general paving mixture was used on all projects. Roadway geometrics, traffic characteristics and construction practices are thought to be contributing factors. PCC pavements retained high skid-resistance during early life--to about two million vehicle passes. Loss of texture, accelerated by studded tires, expose coarse aggregates which polish more readily than the sand-cement matrix. PCC pavements containing dolomitic glacial gravel were conspicuously more slippery than pavements containing a variety of limestones. Deslicking treatments will be needed on interstate roads before they have fulfilled their 20-year design life.

Sand-asphalt surfaces, composed of not less than 50 percent quartz and a significant percentage of limestone sand, did not exhibit the desired level of friction. Several experimental sand-asphalts without limestone sand showed improved skid resistance, but were judged not to be suitable for deslicking purposes on roadways carrying high-speed traffic. However, the need for thin-layered asphalt surface course remains, and the demand for them will grow. Further development of such surfaces, containing hard, angular, silica sands and other aggregate types recognized for their high skid-resistance properties hold promise.

Slipperiness of pavements is an insidious peril. In time, the development of improved surface courses will surely provide needed remedies. In the interim, constraints upon the driver offers some hope of reducing accidents. Legal restraints on speed during wet weather remains a reasonable but untried safety precaution.

## ACKNOWLEDGMENT

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The contents of this paper reflects the views of the authors and not necessarily the official views of policies of the Kentucky Department of Highways or the Federal Highway Administration.

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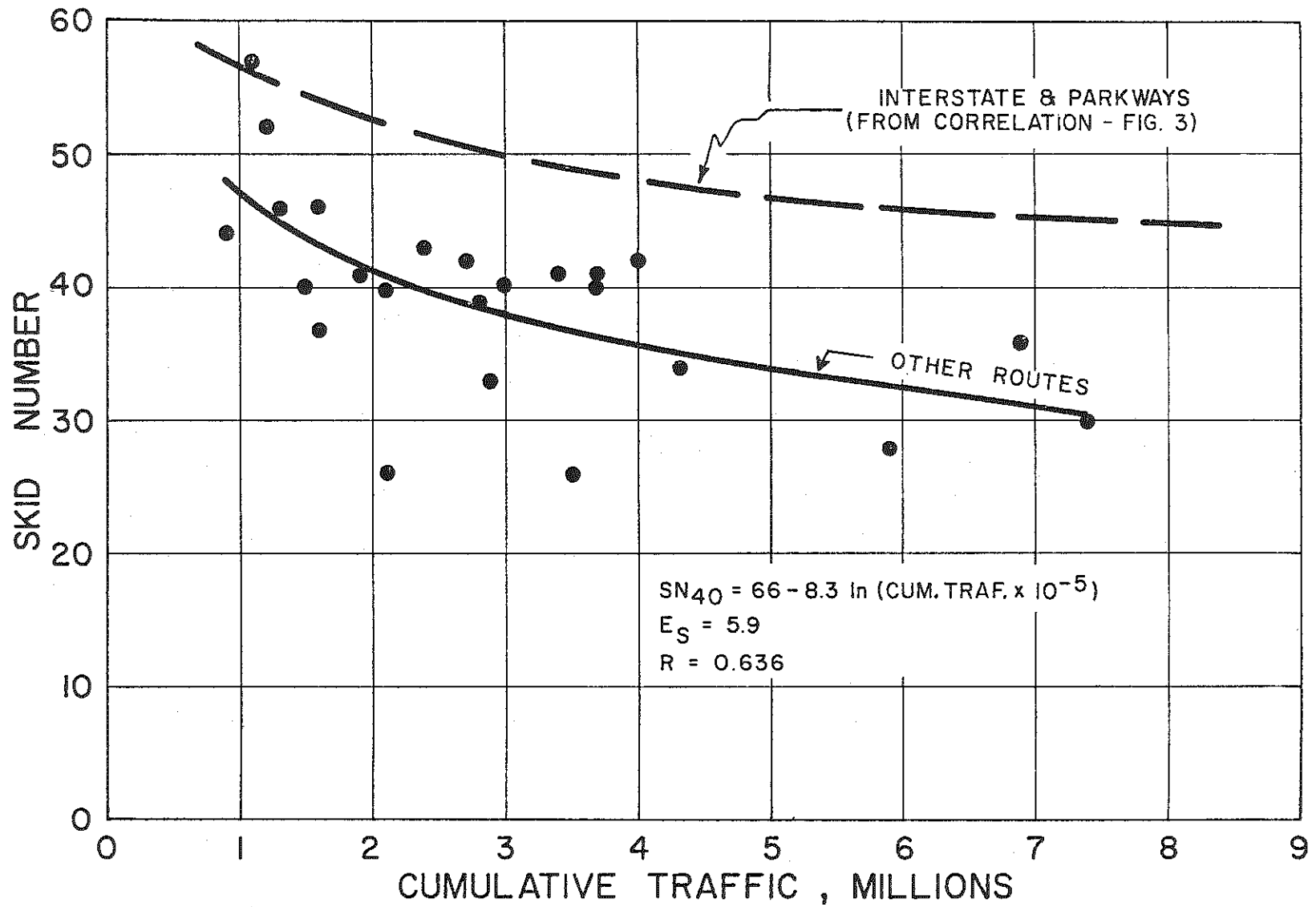


Figure 1. Effect of Traffic on Asphaltic Concrete Surfaces; US and KY Routes.



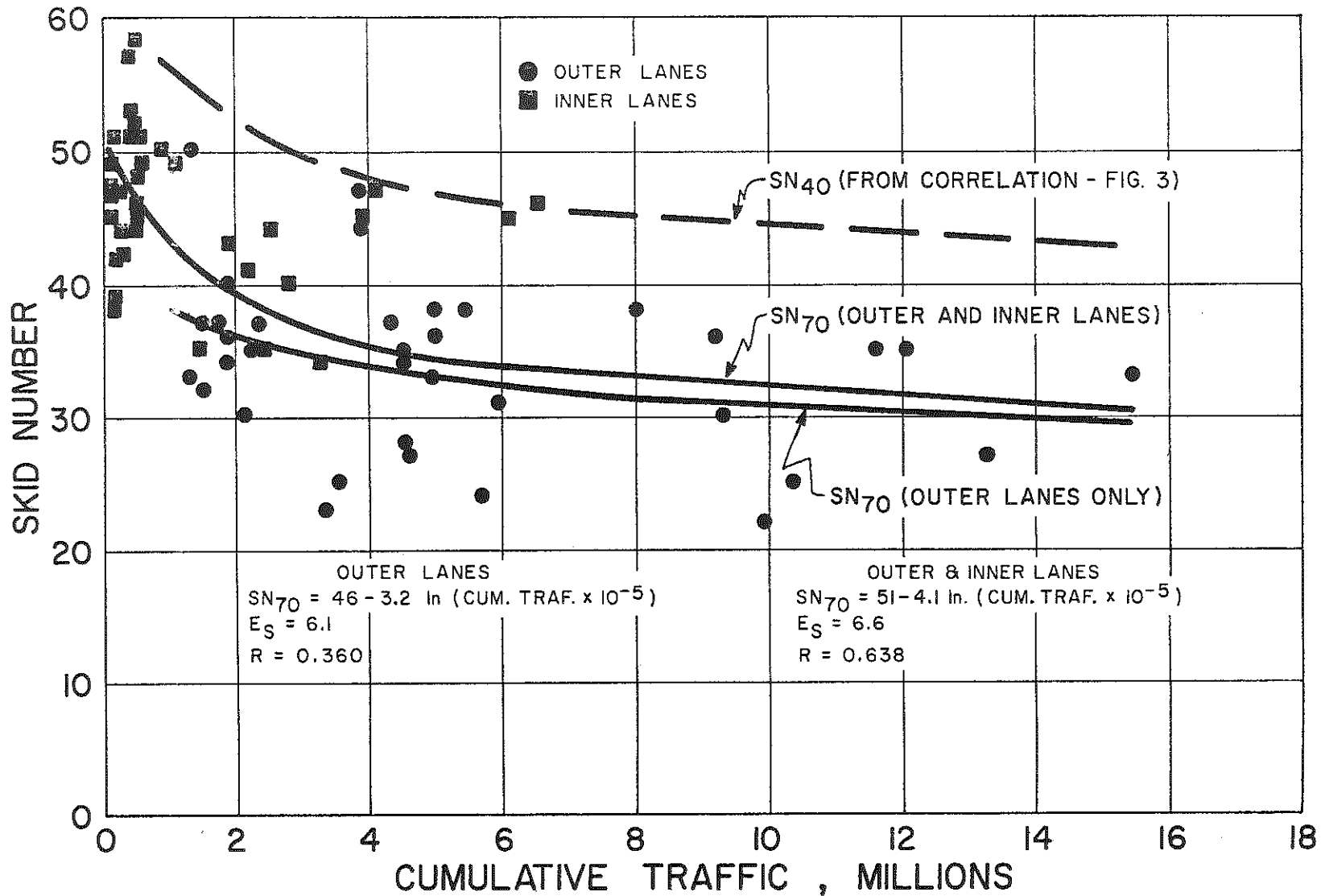


Figure 2. Effect of Traffic on Asphaltic Concrete Surfaces; Interstate and Parkway Routes.

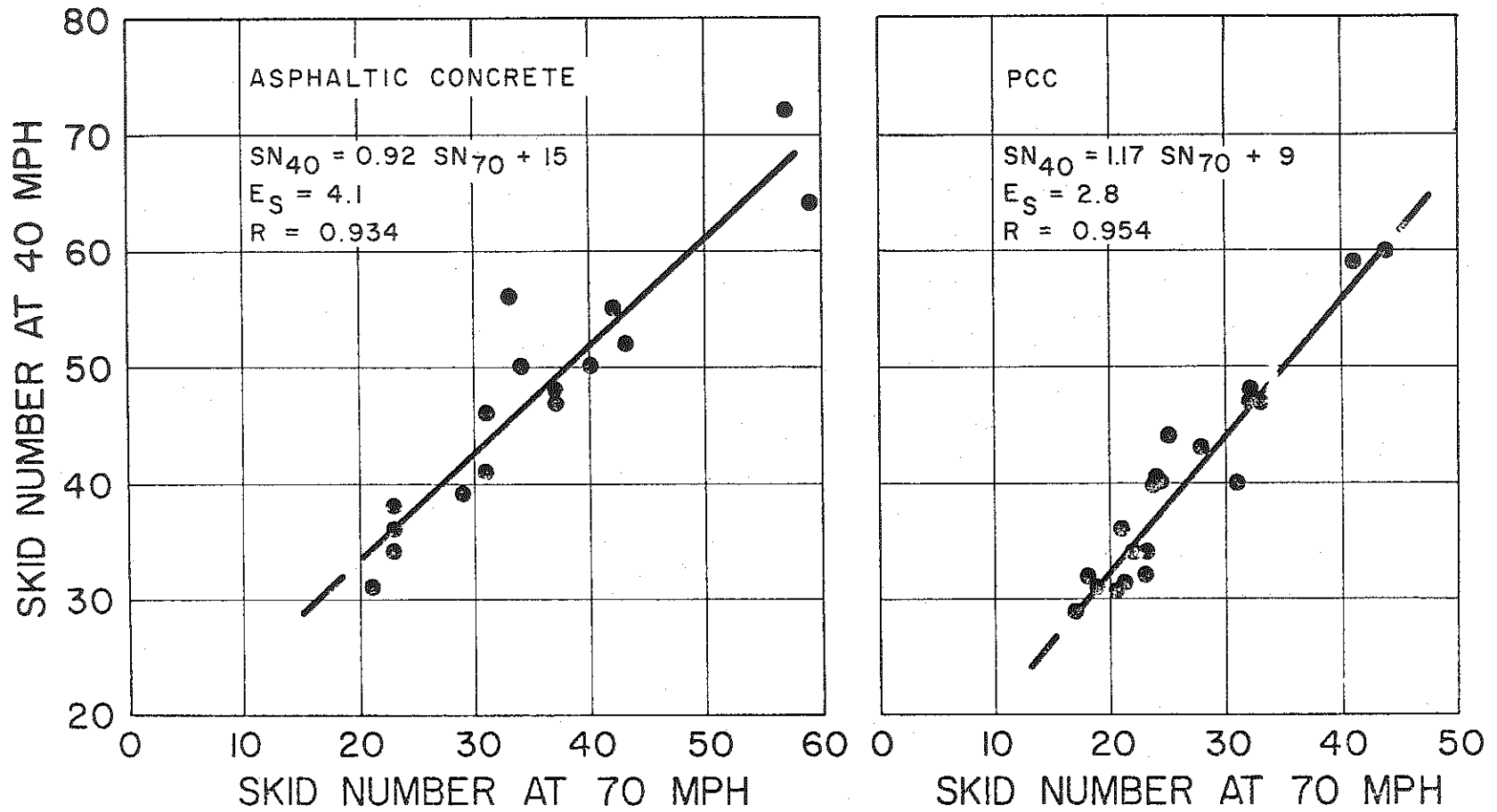


Figure 3. Correlation of Trailer Tests Conducted at 40 mph and 70 mph on Asphaltic Concrete and PCC Pavements; Interstate and Parkway Routes.

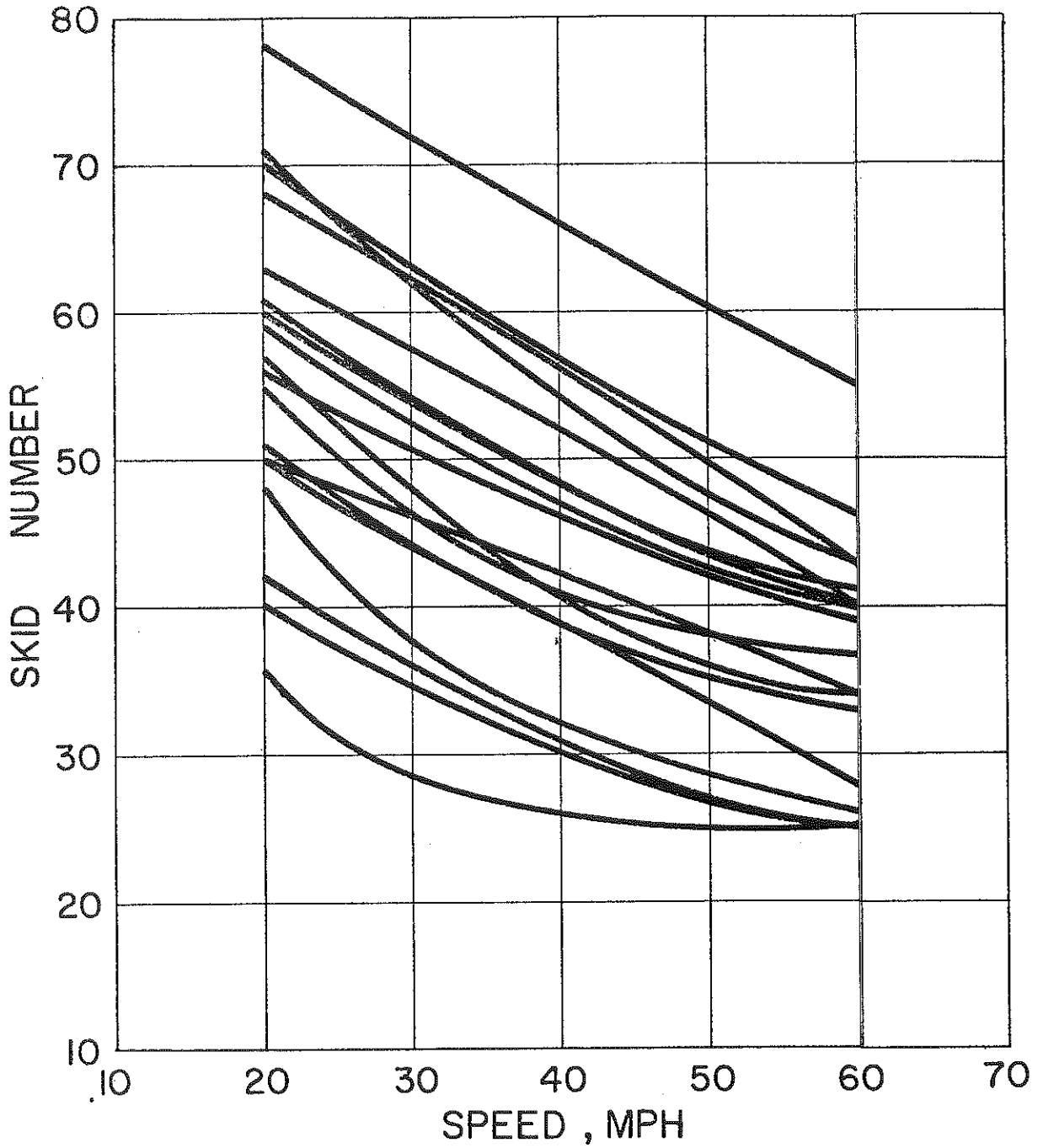


Figure 4. Effect of Speed on Skid Resistance of Asphaltic Concrete Pavements.

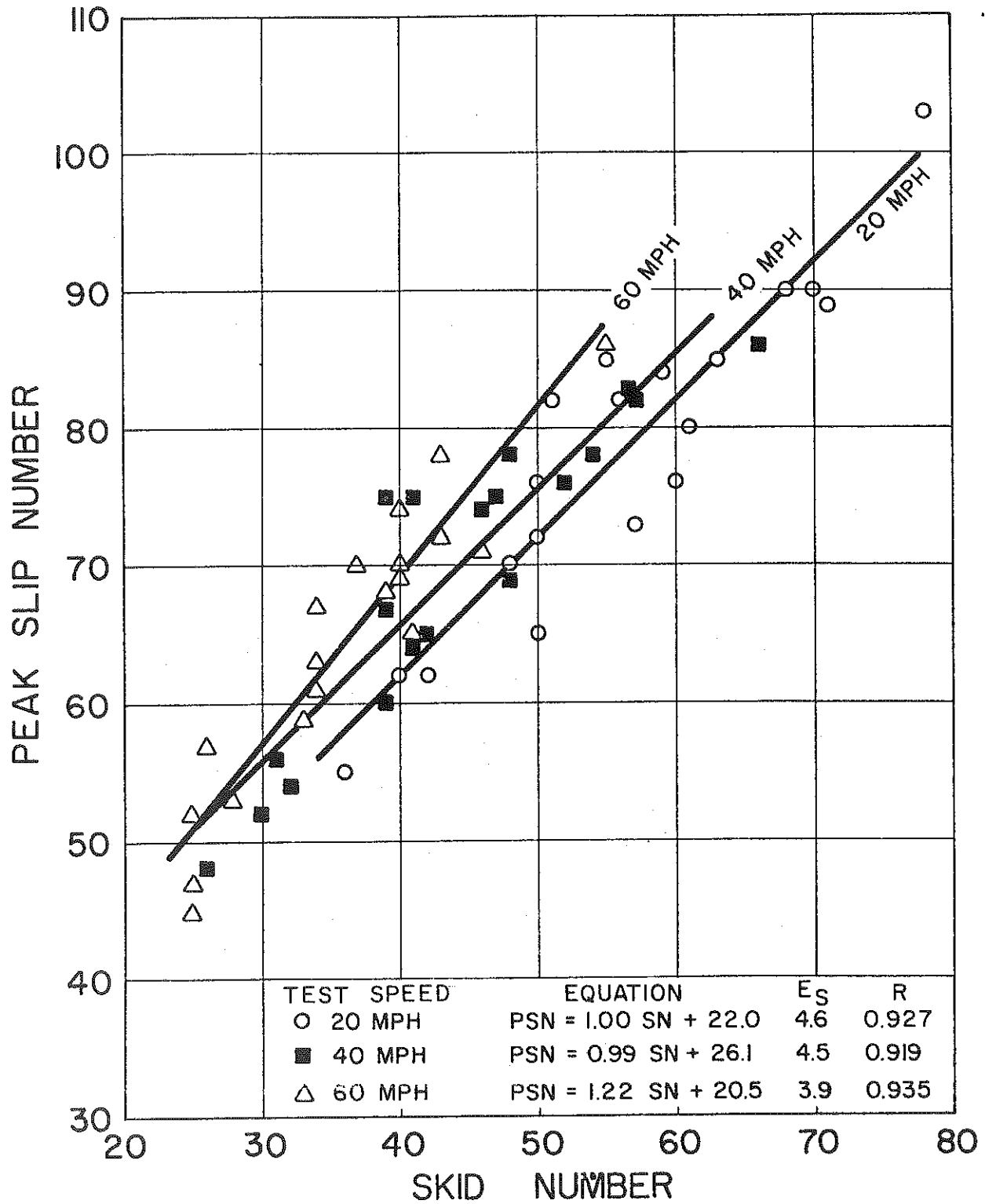


Figure 5. Relationship between Peak Slip Number and Skid Number of Asphaltic Concrete Pavements.

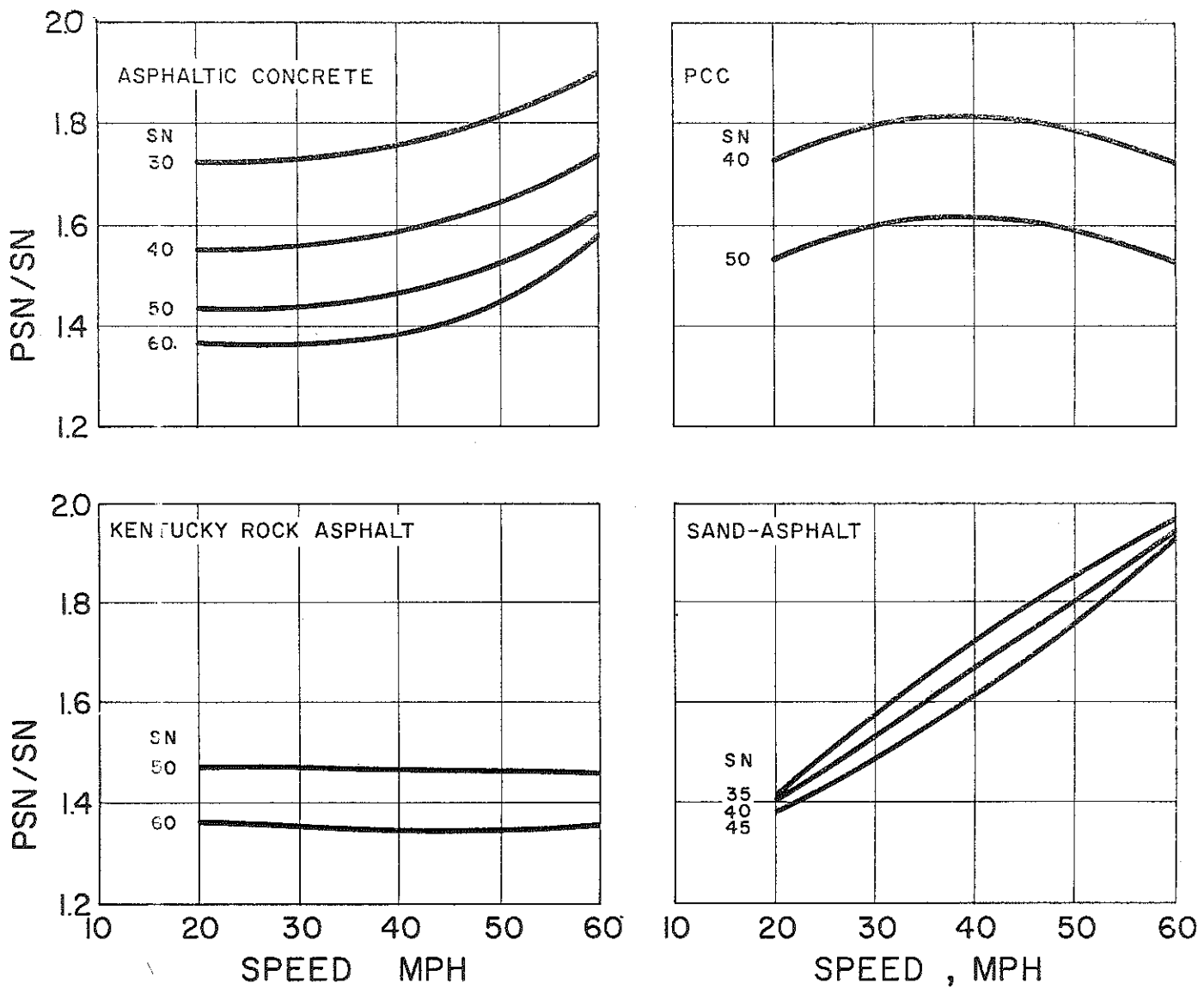


Figure 6. Relationship between PSN/SN and Speed; Several Skid Numbers.

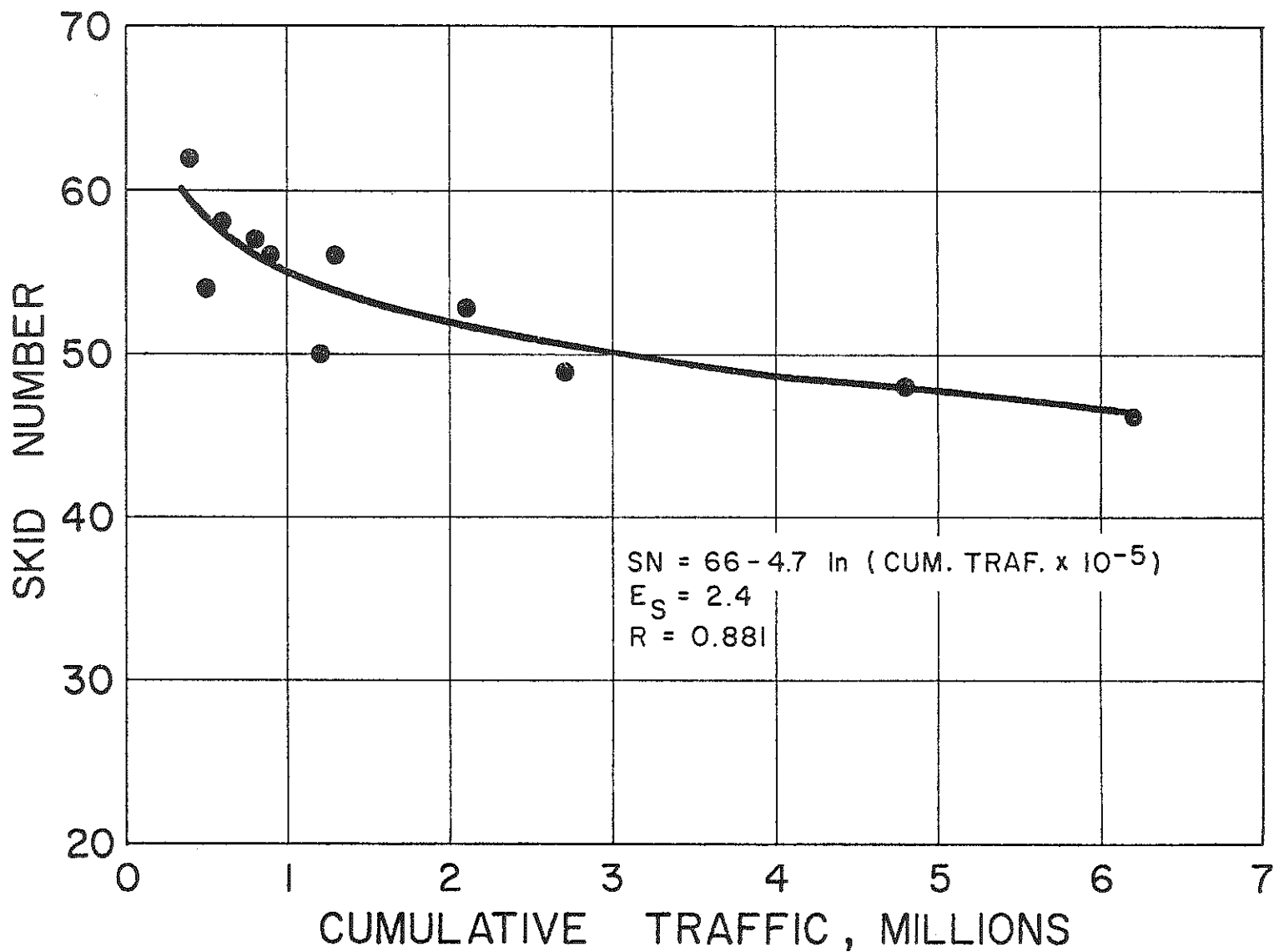


Figure 7. Effect of Traffic on Skid Resistance of Kentucky Rock Asphalt Surfaces.

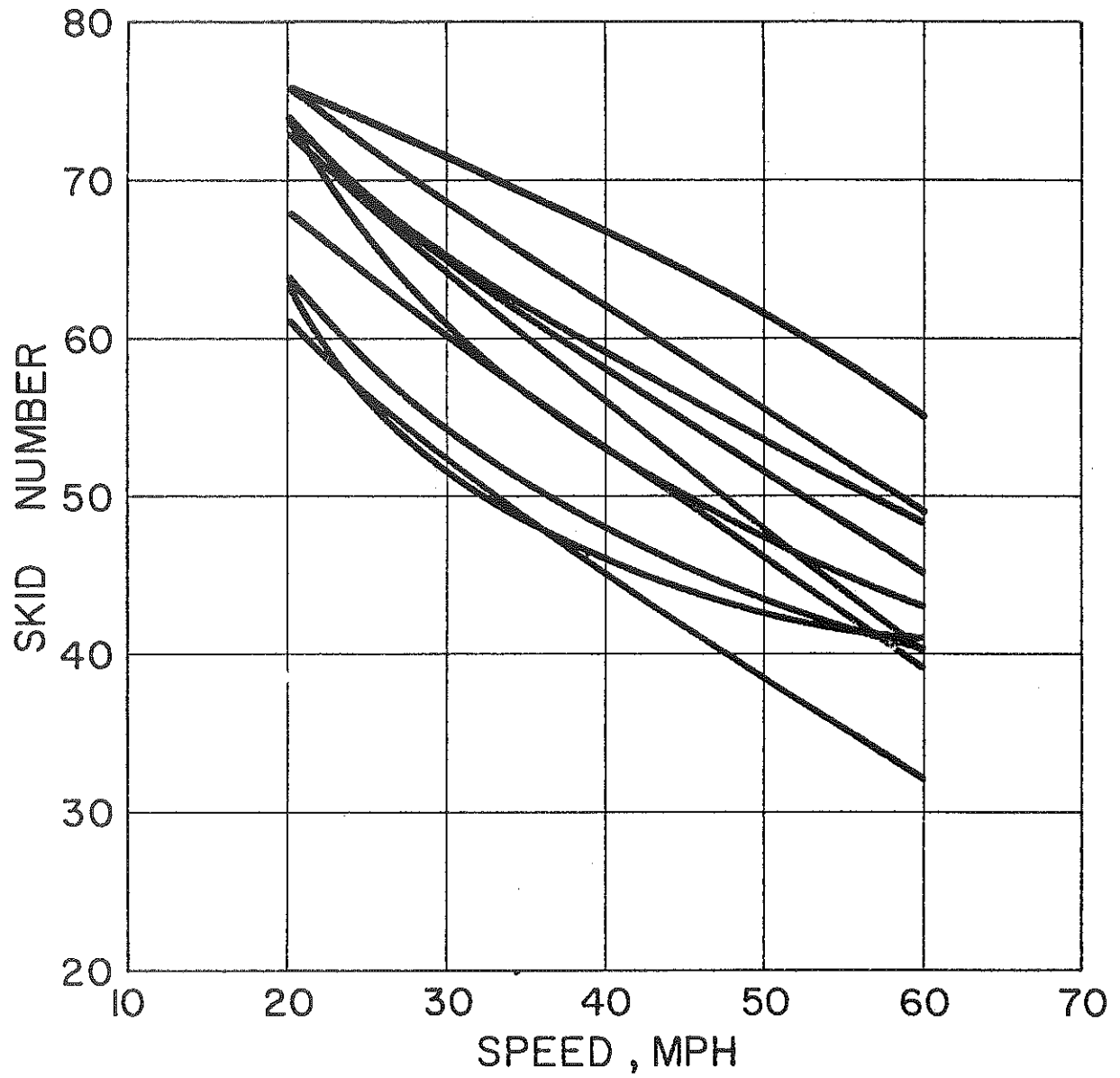


Figure 8. Effect of Speed on Skid Resistance of Kentucky Rock Asphalt Pavements.

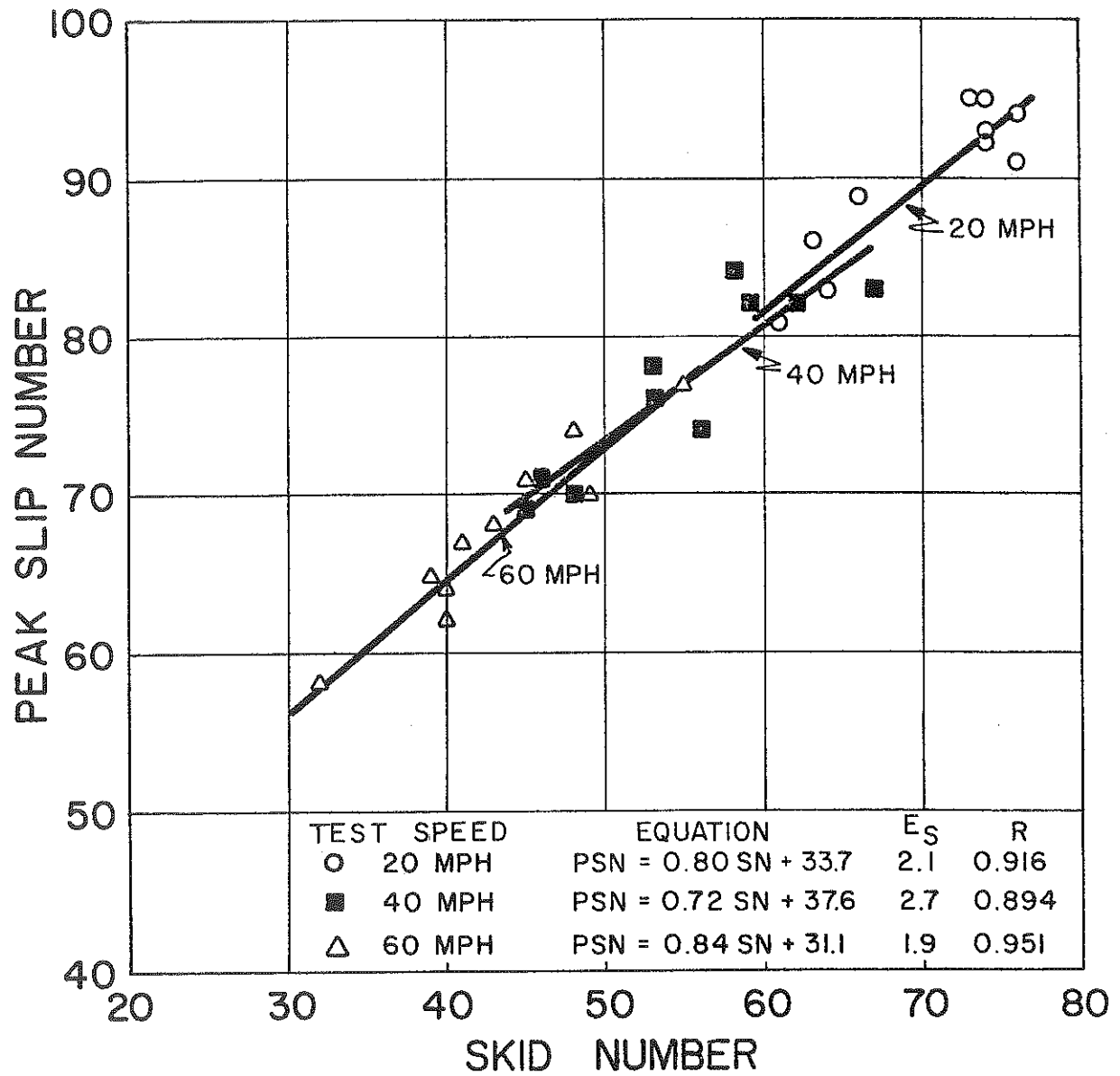


Figure 9. Relationship between Peak Slip Number and Skid Number of Kentucky Rock Asphalt Pavements.



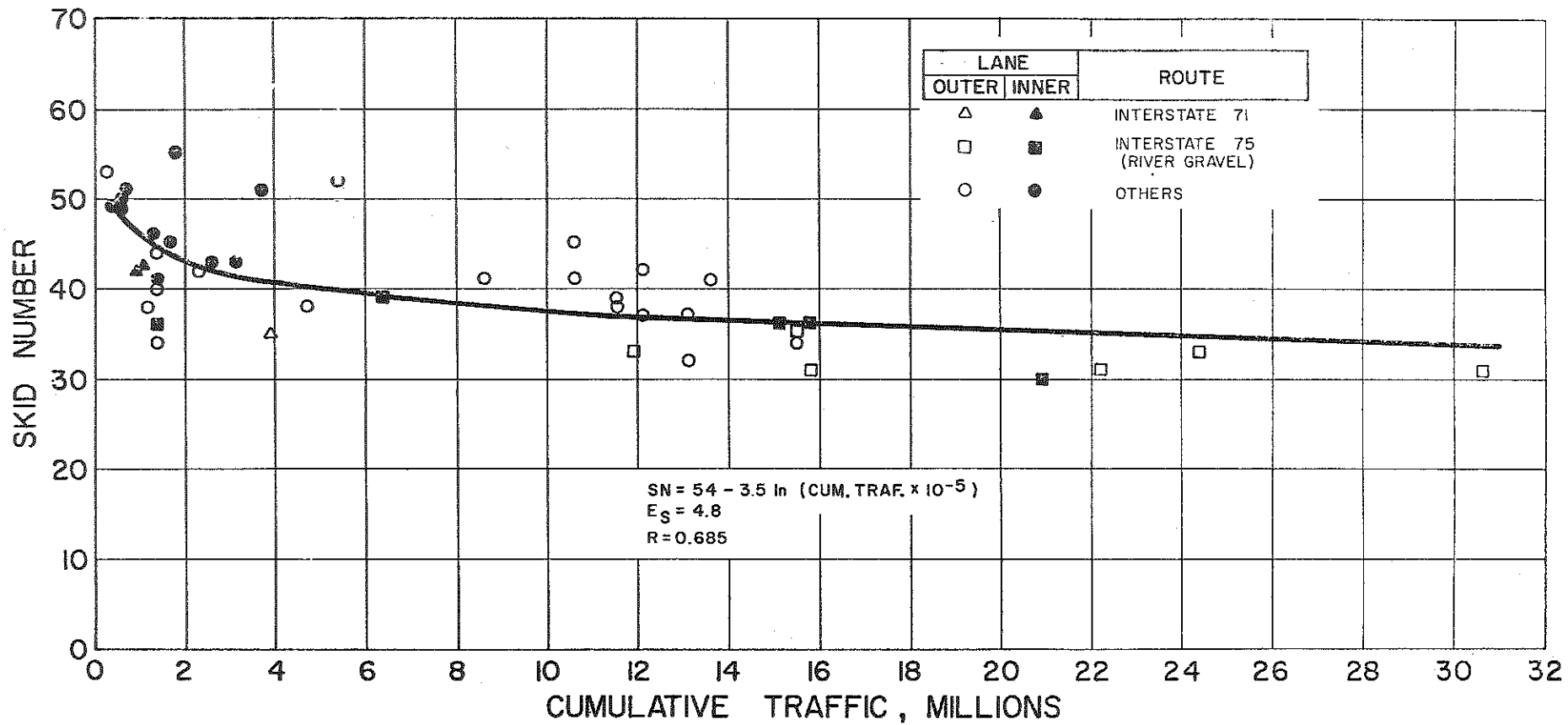


Figure 10. Effect of Traffic on Skid Resistance of PCC Pavements.

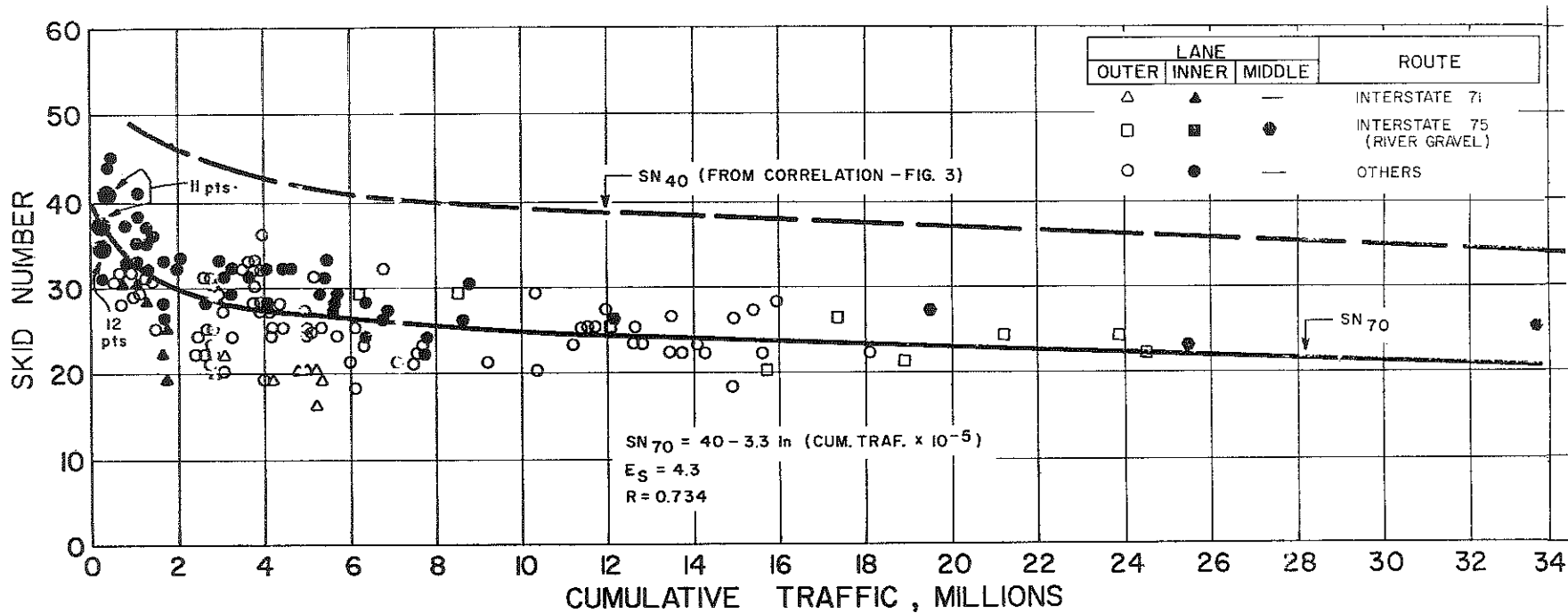


Figure 11. Effect of Traffic on Skid Resistance of PCC Surfaces; Interstate and Parkway Routes (70 mph).

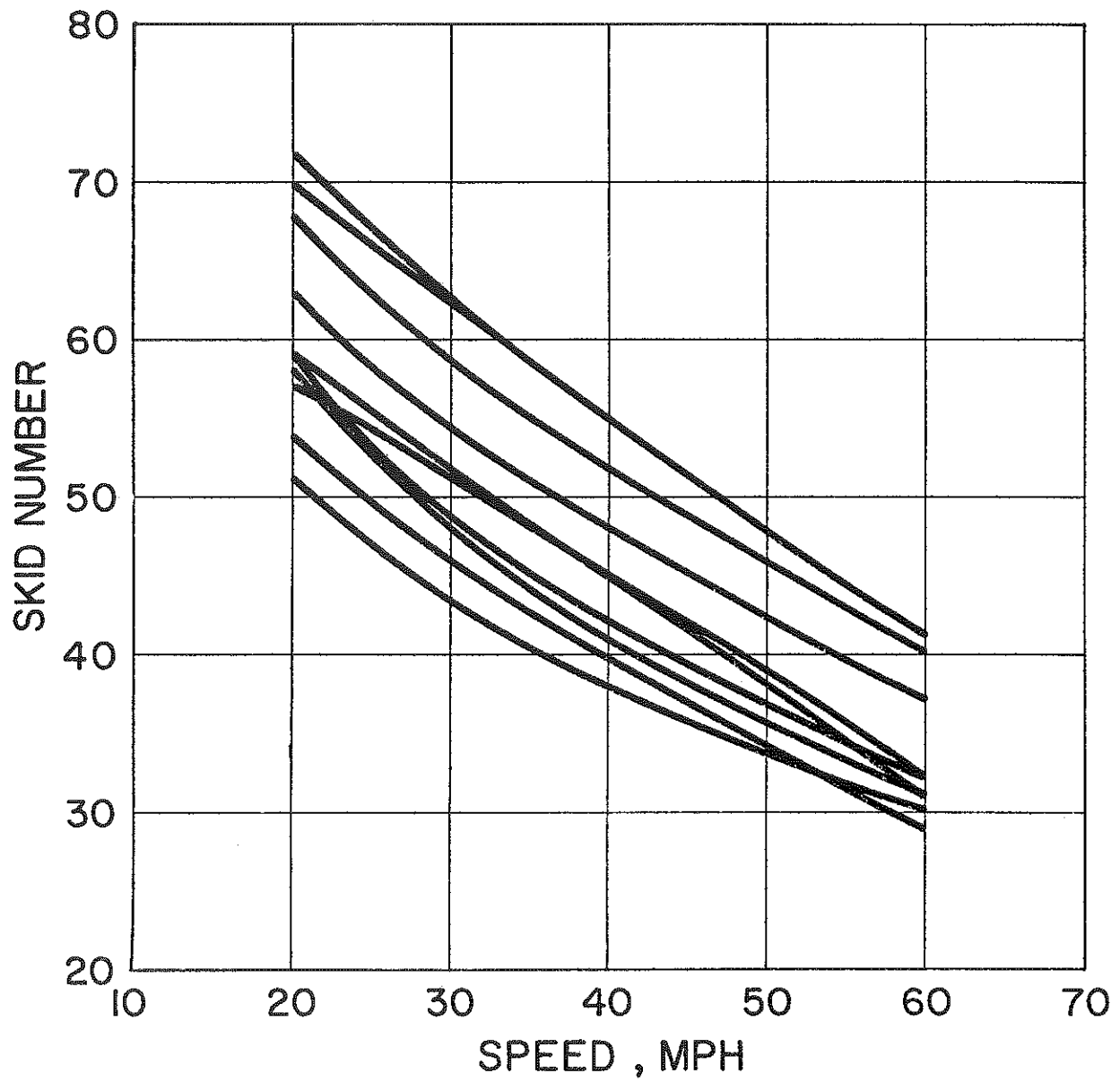


Figure 12. Effect of Speed on Skid Resistance of PCC Pavements.

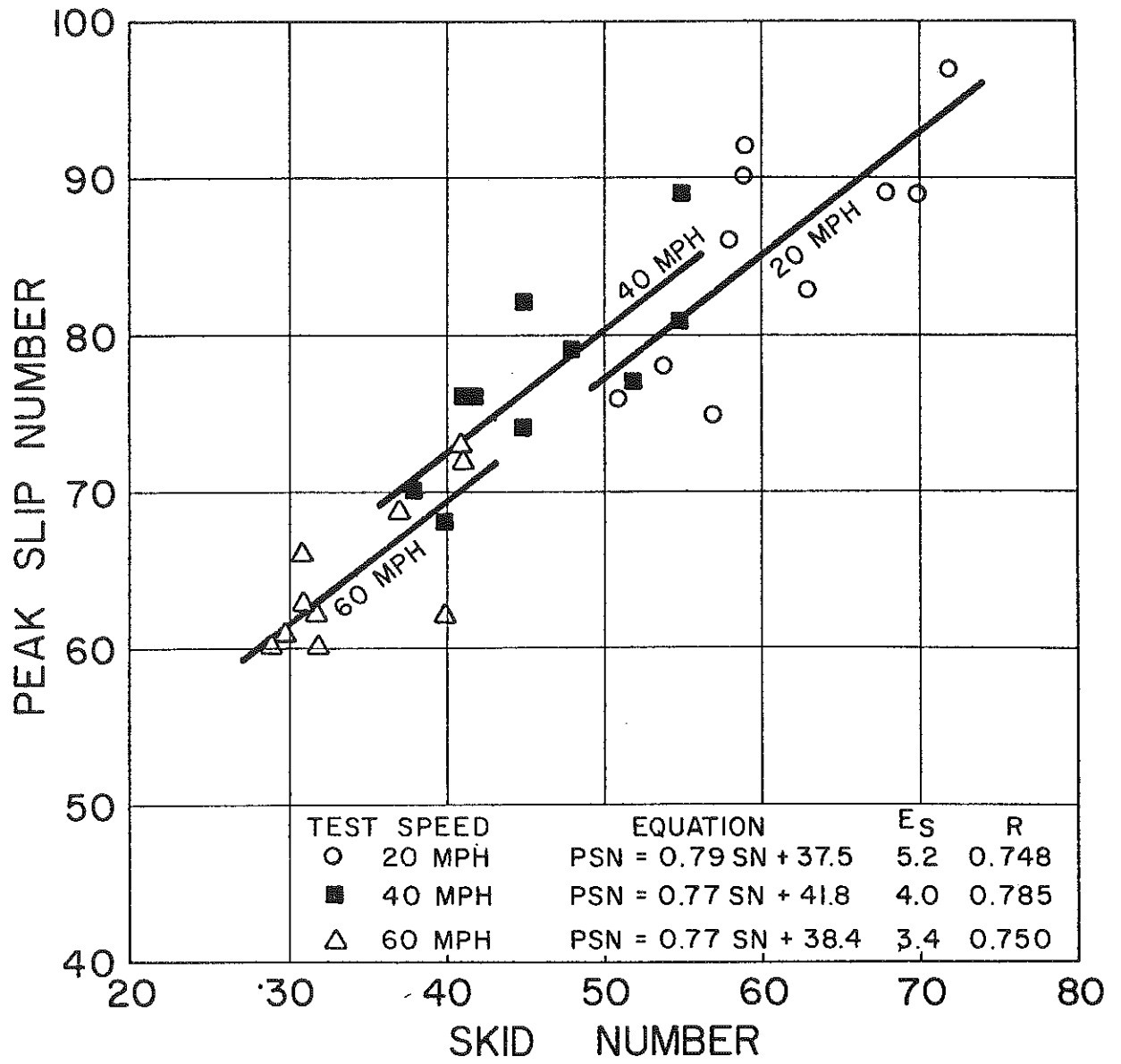


Figure 13. Relationship between Peak Slip Number and Skid Number; PCC Pavements.

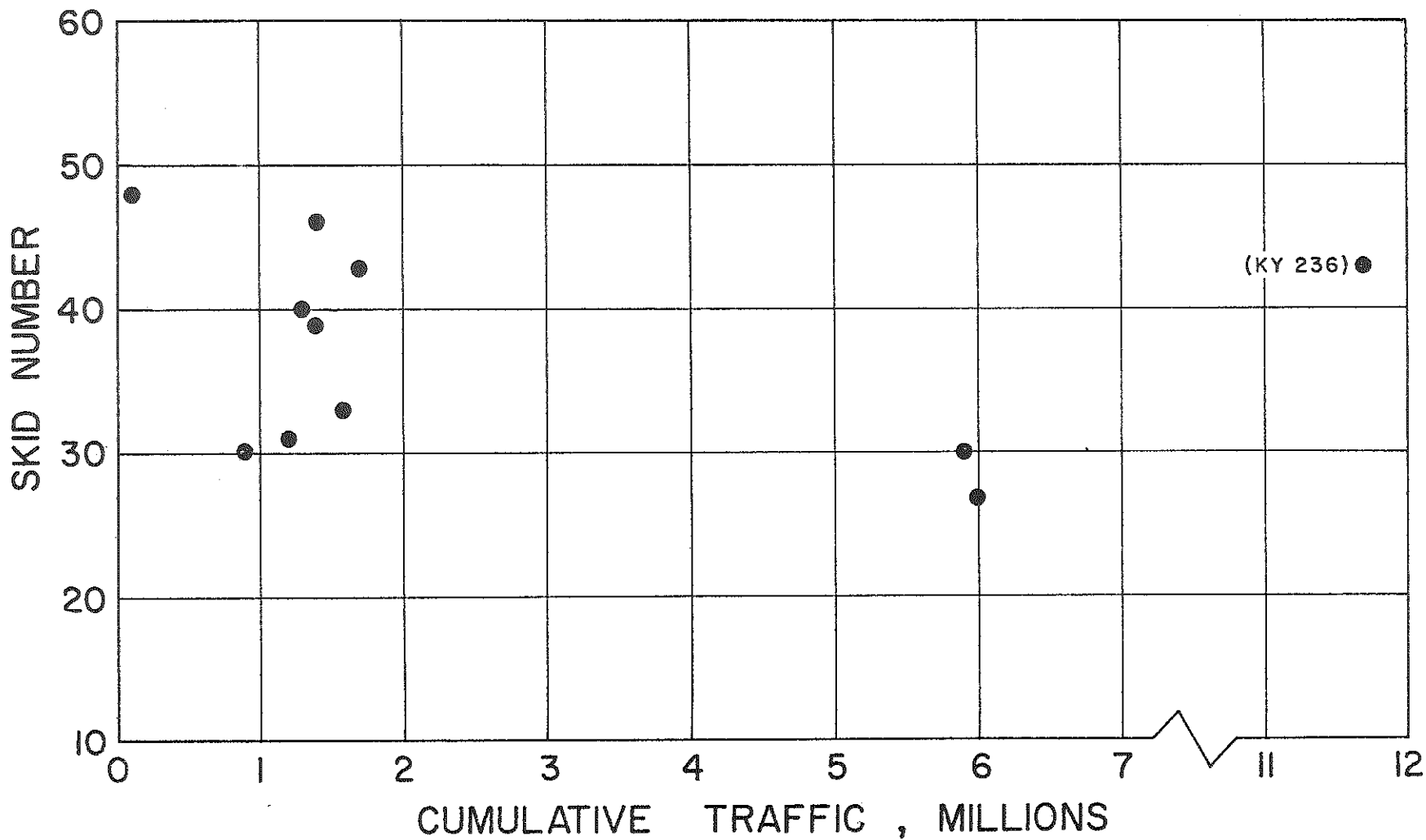


Figure 14. Effect of Traffic on Skid Resistance of Sand-Asphalt Surfaces.

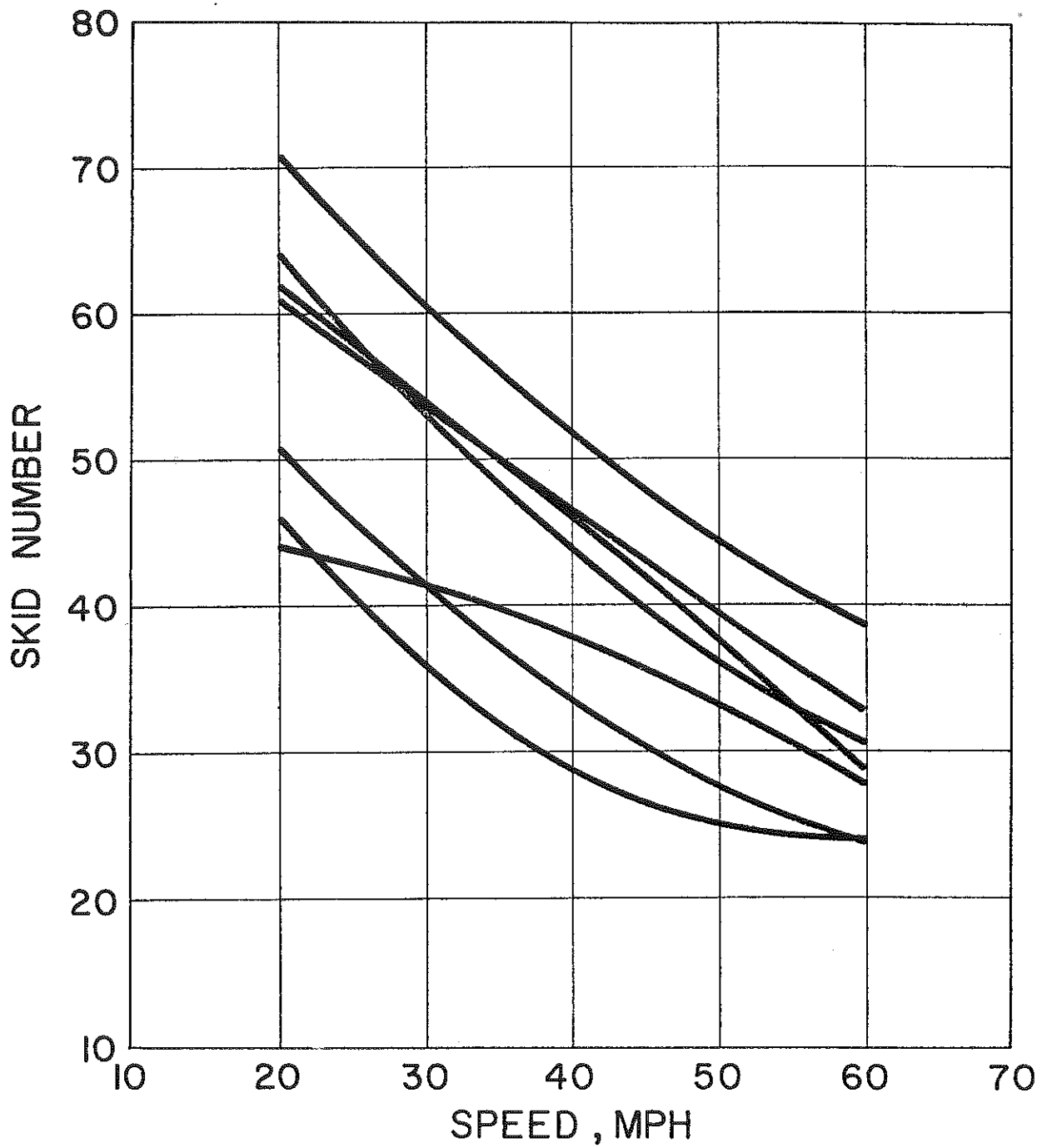


Figure 15. Effect of Speed on Skid Resistance of Sand-Asphalt Surfaces.

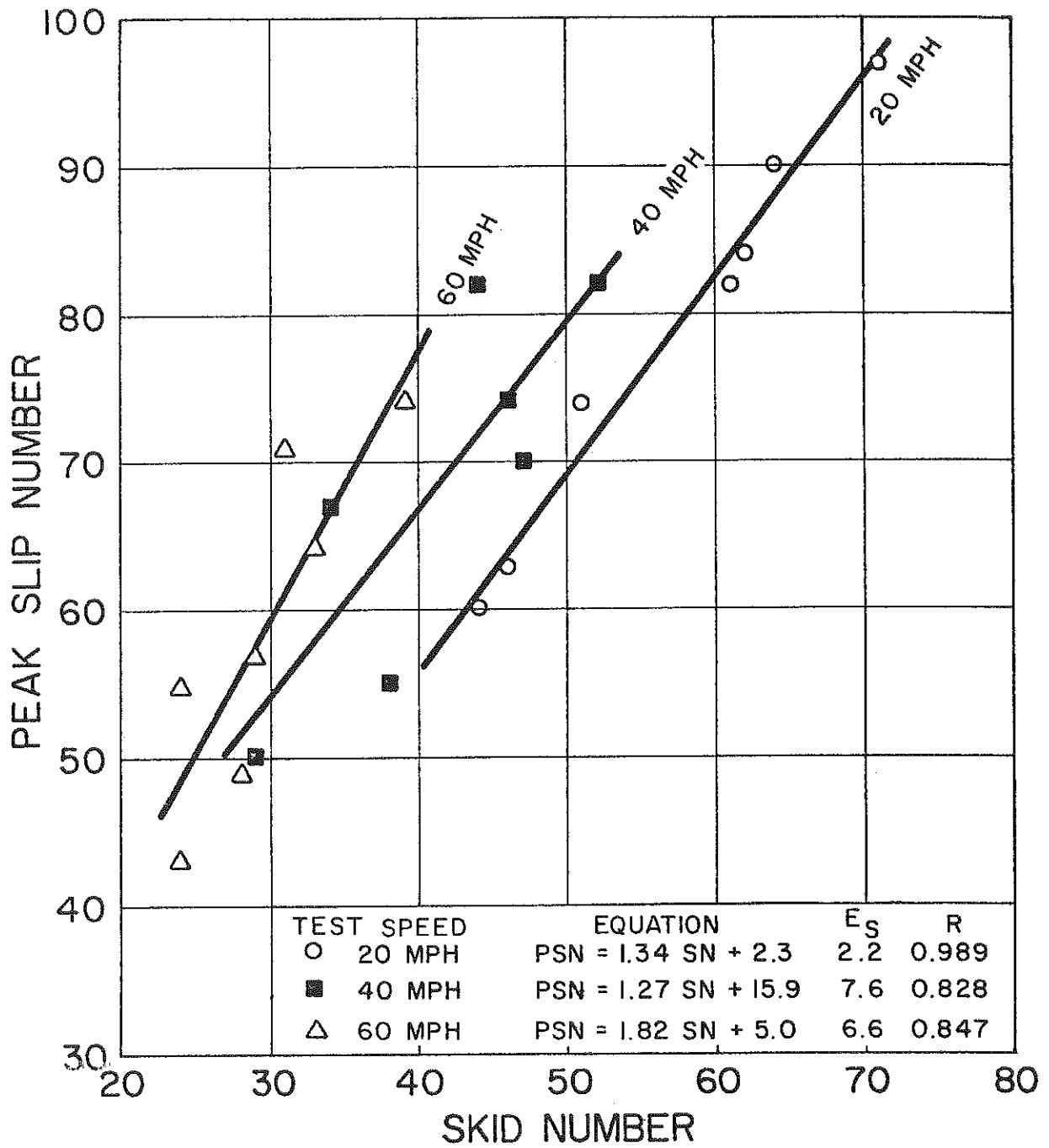


Figure 16. Relationship between Peak Slip Number and Skid Number of Sand-Asphalt Surfaces.

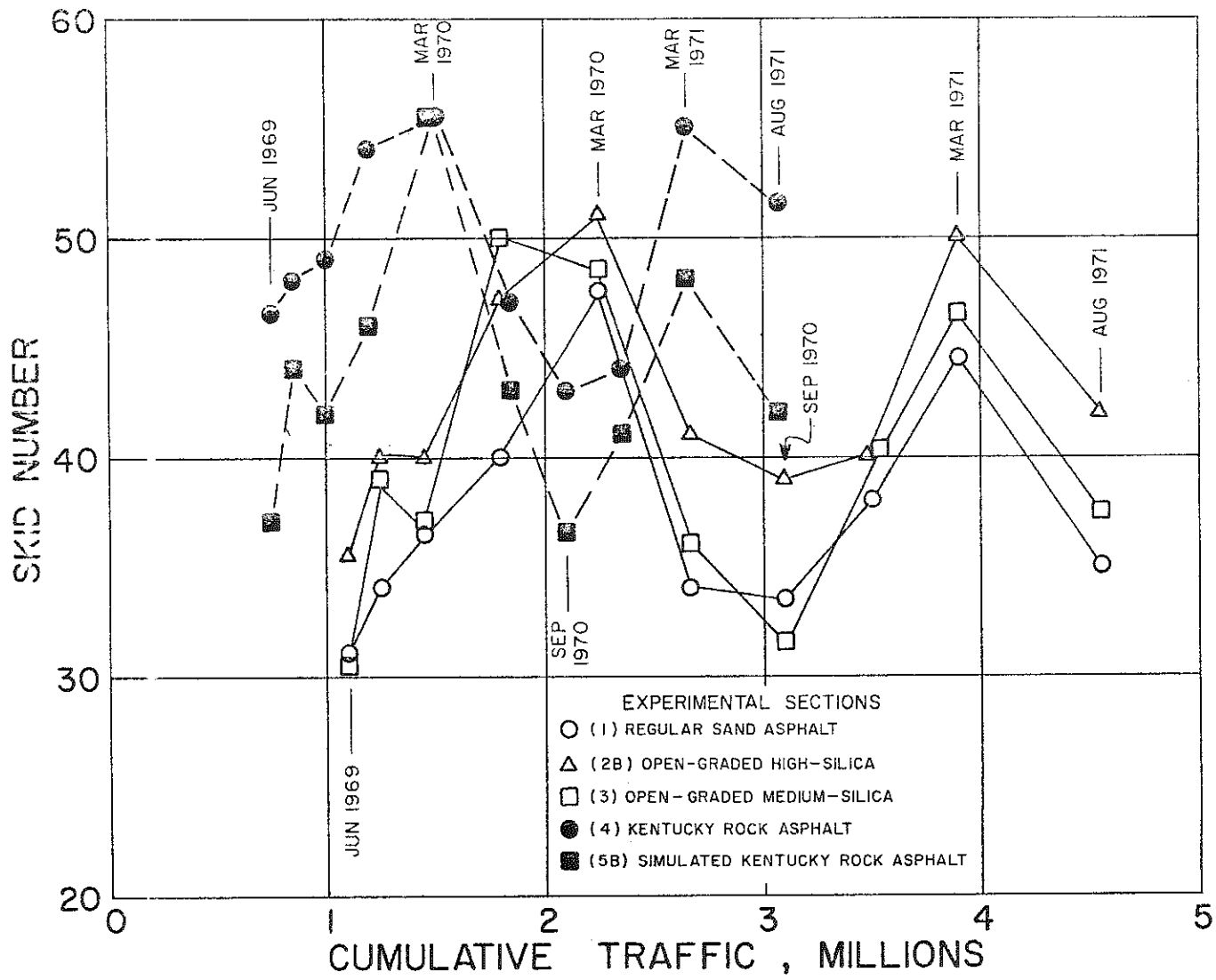


Figure 17. Effect of Traffic on Skid Resistance of Experimental Sand-Asphalt in Pulaski County.



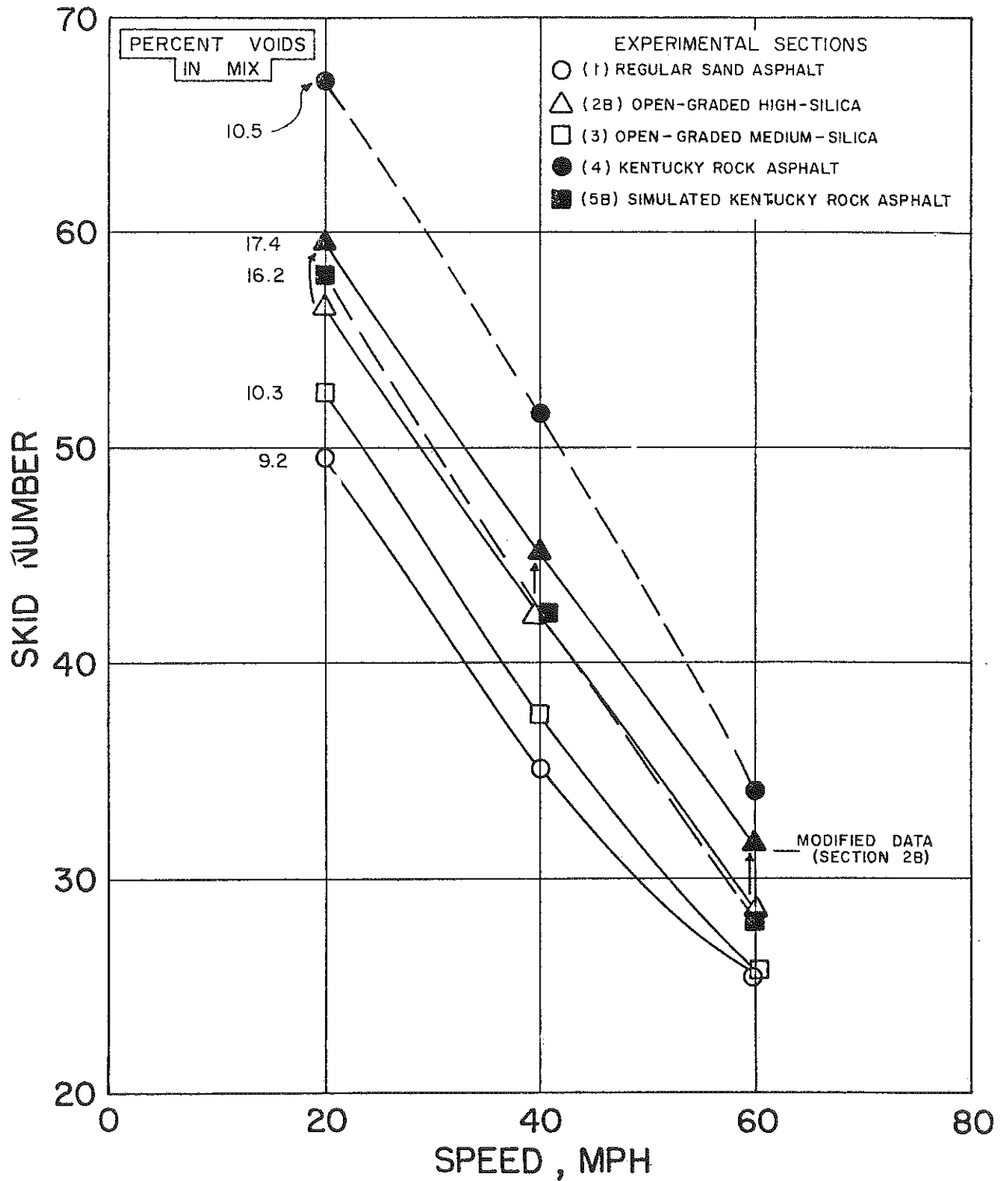


Figure 18. Skid Resistance of Experimental Sand-Asphalt Sections in Pulaski County; Three Test Speeds (August 1971).

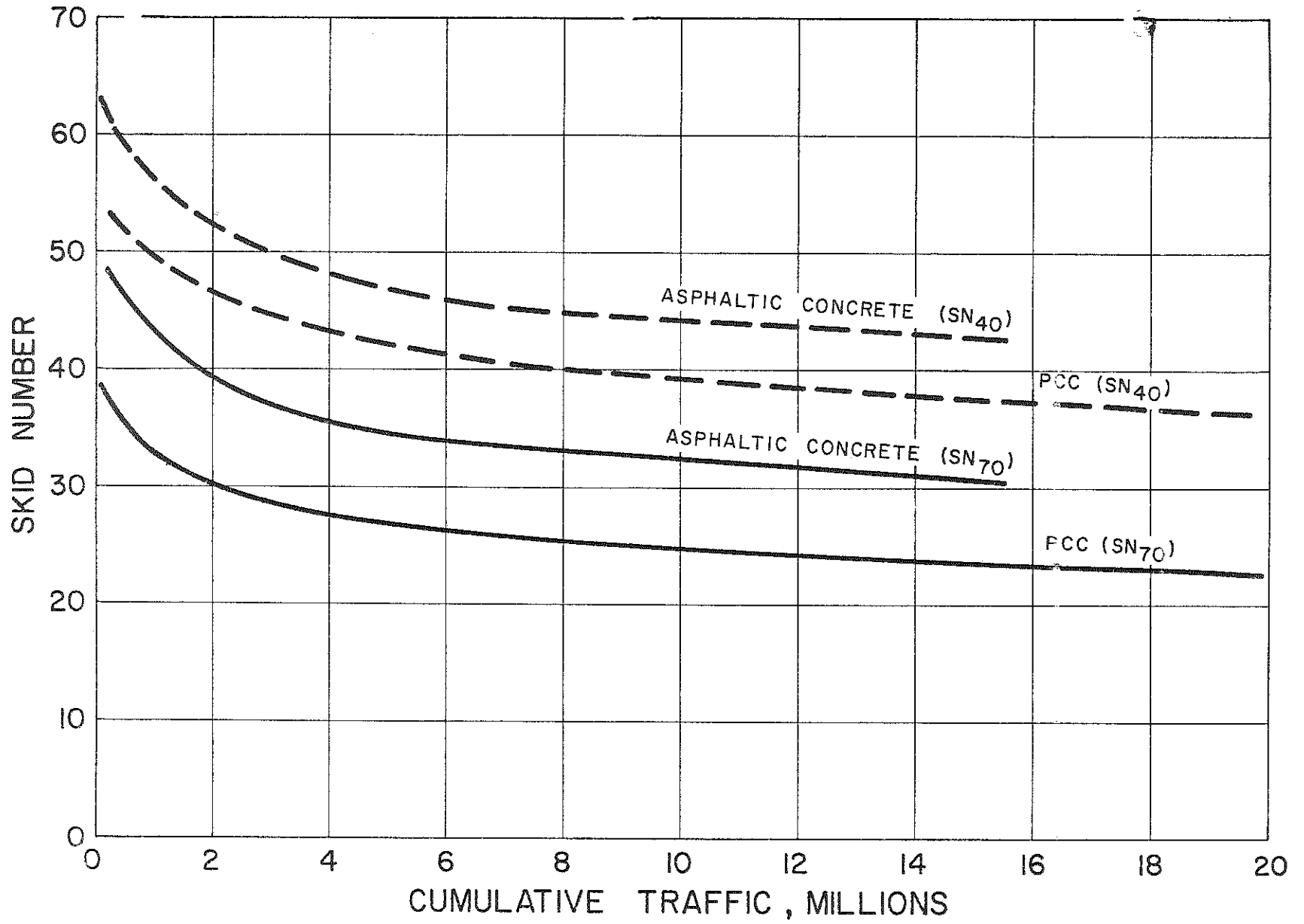


Figure 19. Comparison of Asphaltic Concrete Pavements and PCC Pavements; Interstate and Parkway Routes.

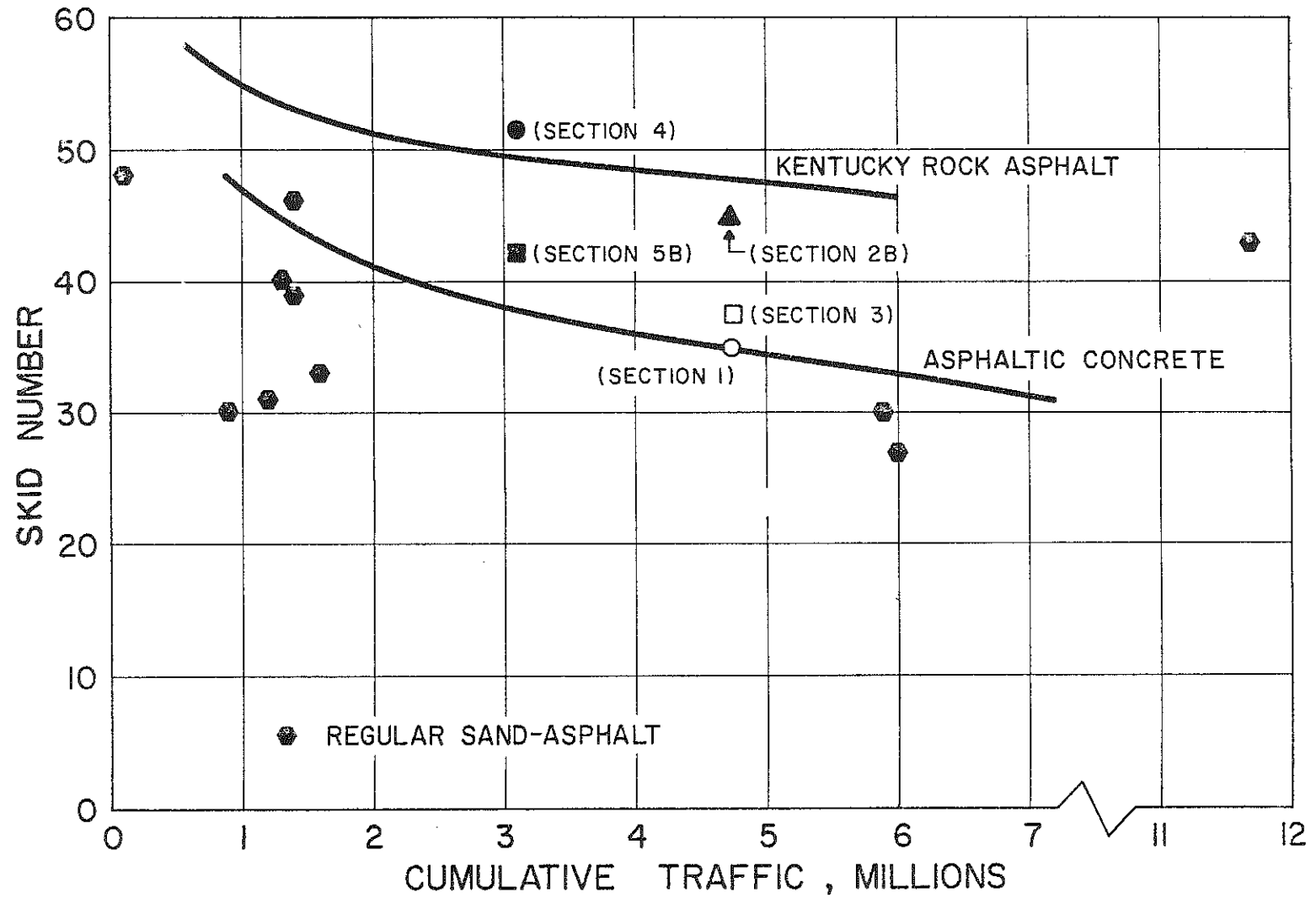


Figure 20. Comparison of Several Types of Bituminous Surfaces on US and KY Routes.

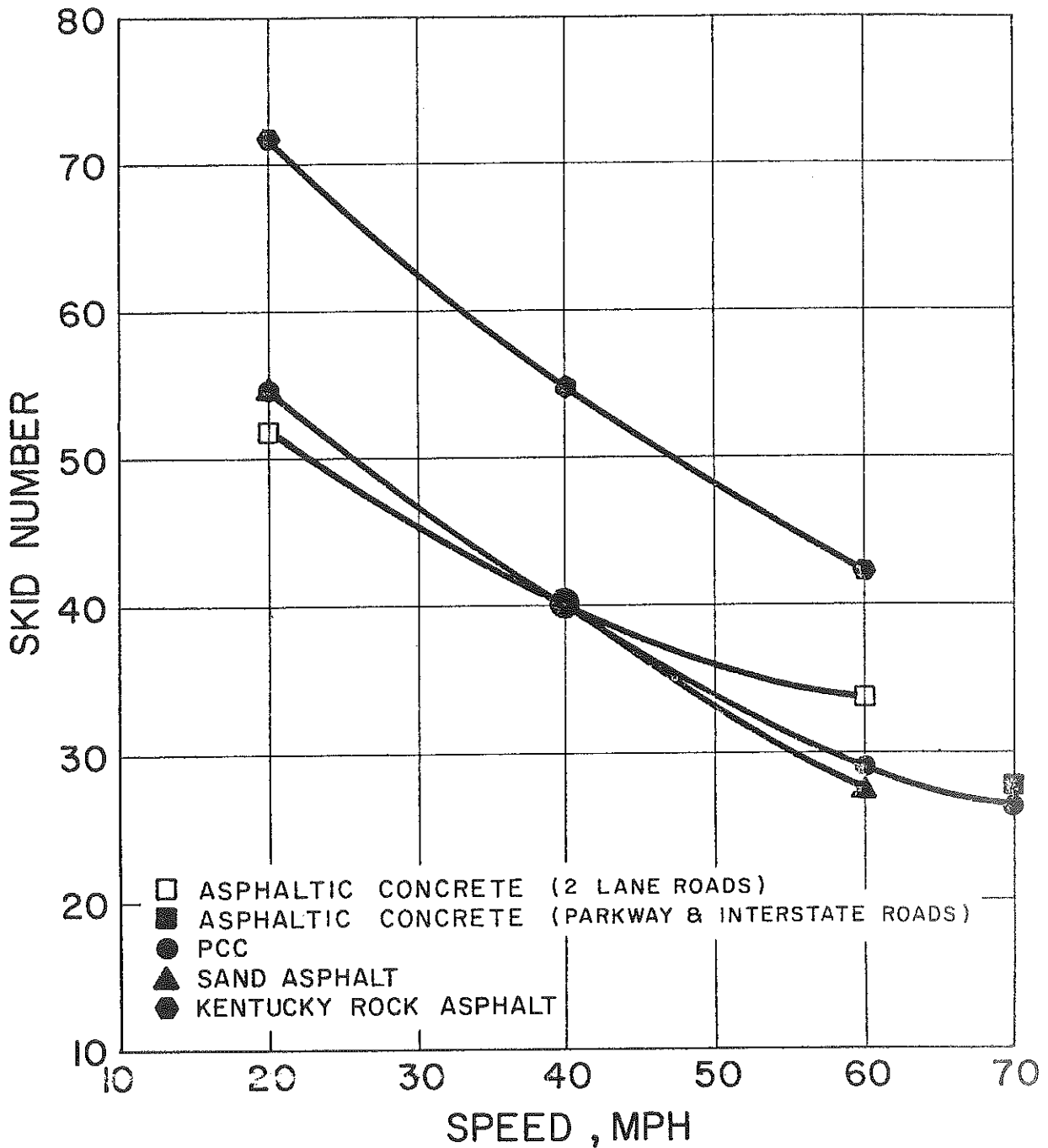


Figure 21. Effect of Speed on Skid Resistance; Several Pavement Types.

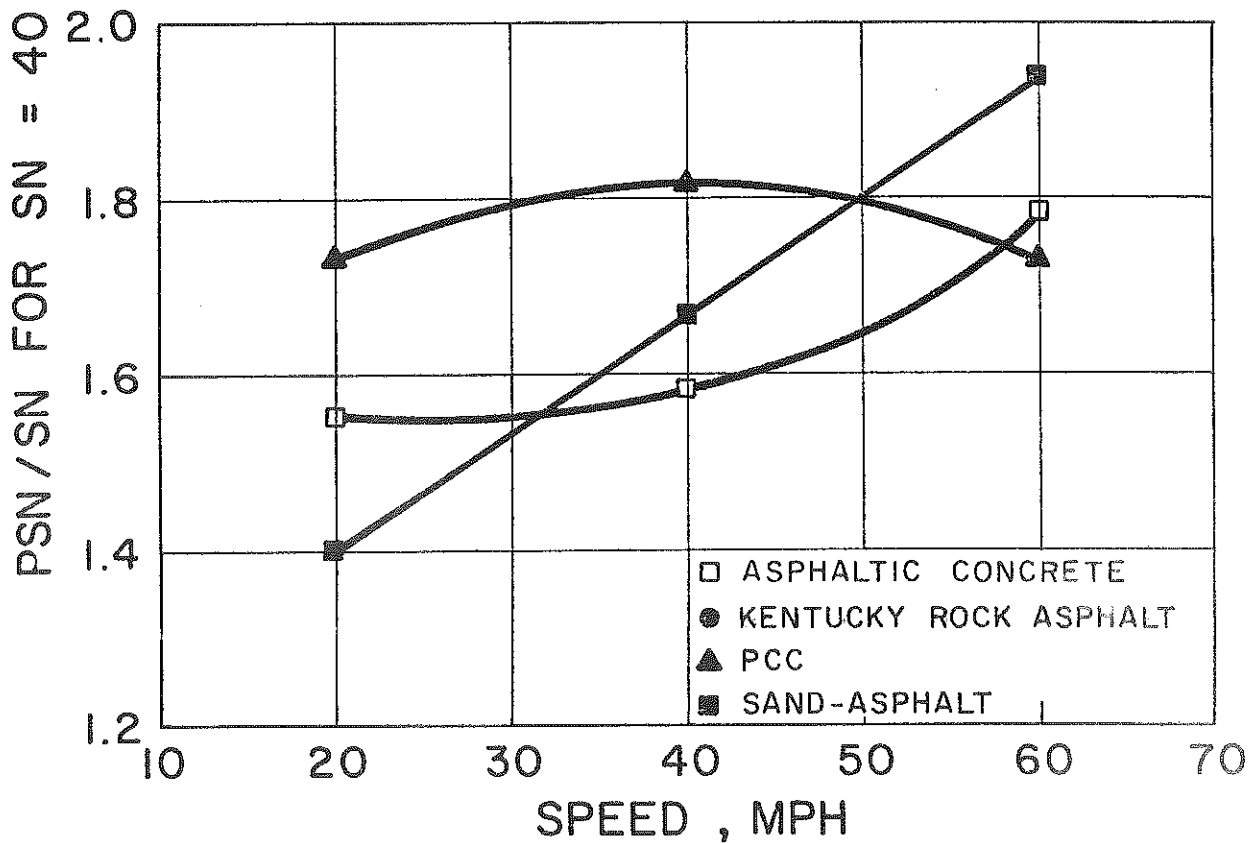
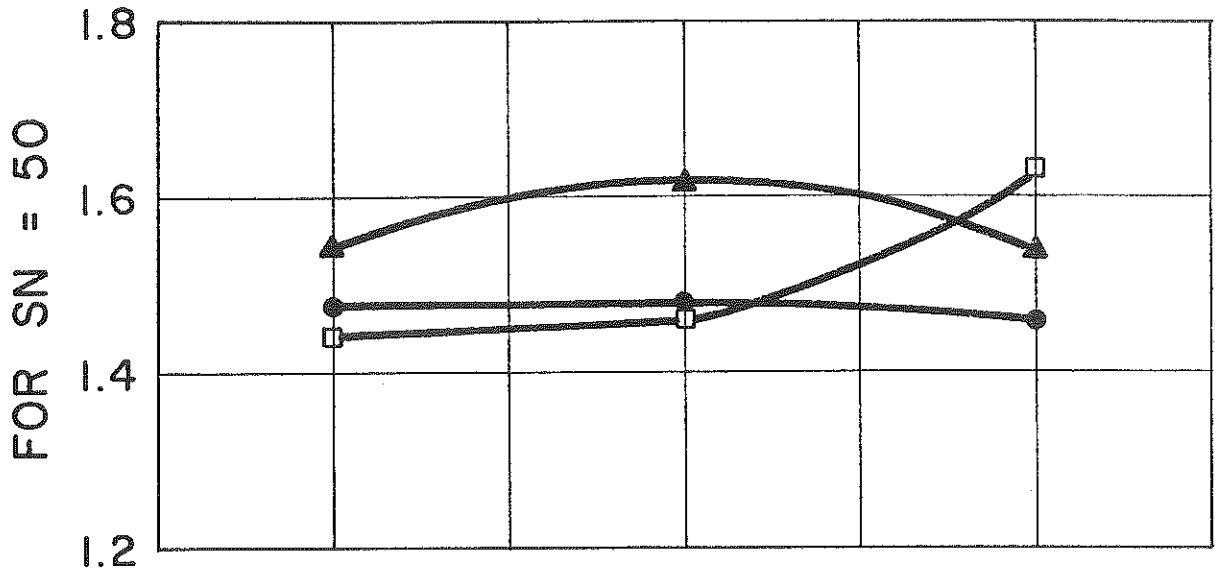


Figure 22. Relationship between PSN/SN Ratio and Speed; Several Pavement Types.

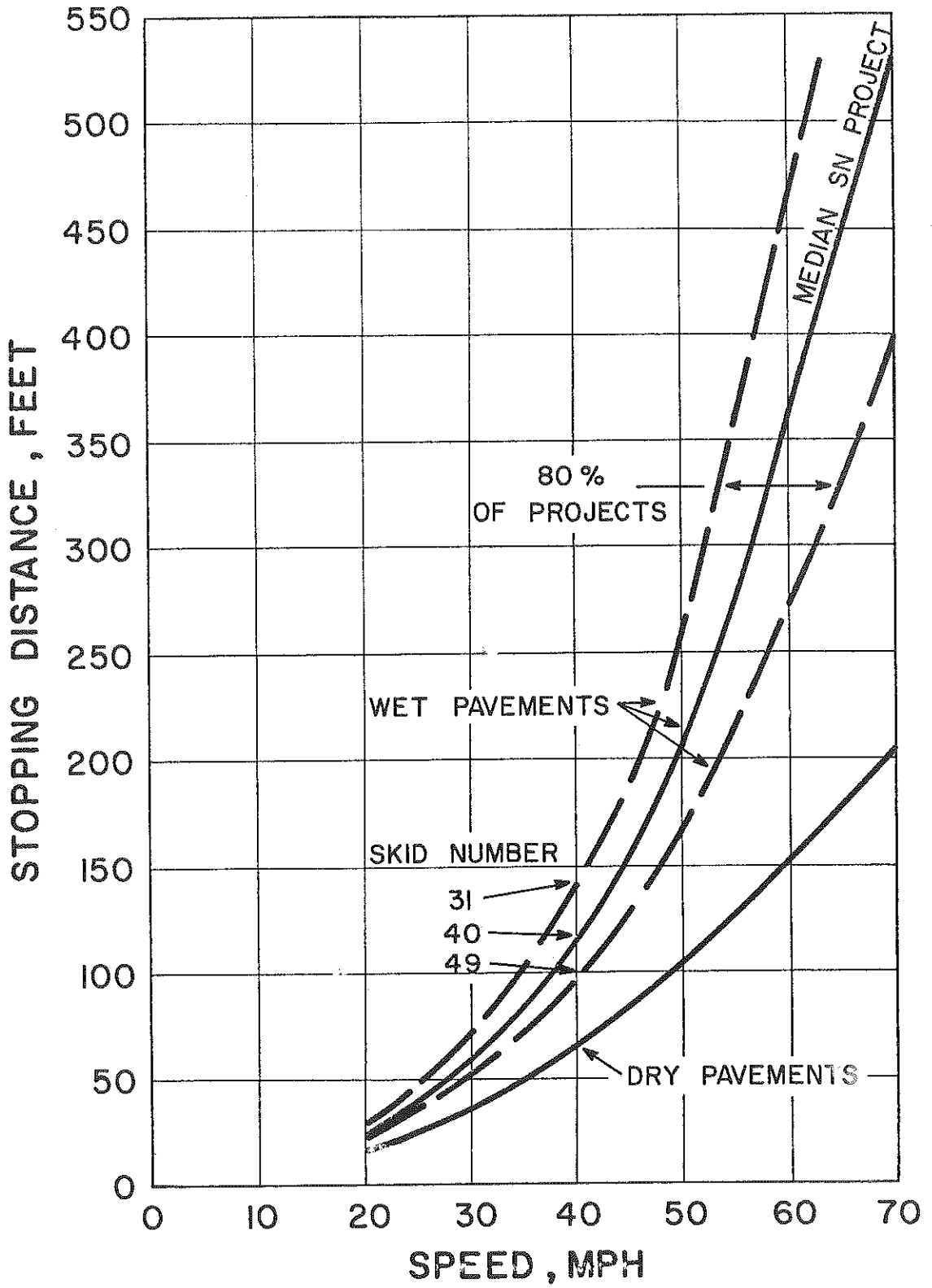


Figure 23. Comparison of Stopping Distances on Wet Pavements, Based on Trailer Tests of 430 Projects, with Stopping Distances on Dry Pavements.