Development and Results of a Skid Research And Road Inventory Program in Pennsylvania

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The Pennsylvania Department of Highways initiated a statewide annual skid survey in 1963 using the single-wheel skid trailer developed at Pennsylvania State University. Five of these surveys have served to guide the maintenance bureau in providing safer highways, and have contributed to the overall direction of the research program. Data collection methods and testing techniques were perfected during this time and carried over to a more strenuous research program currently in progress. The scope of past and current research, both in-house and department-sponsored, is described briefly.

Results of the five completed surveys have been analyzed. Despite the geographical, hence the aggregate, diversity of statewide data, some relationships formerly only suspected are now apparently established. These results are presented in this paper.

Expansion of Pennsylvania's road inventory and research programs is imminent. New, fully automated skid testers are being acquired; one or two may be assigned to critically located regional offices to maintain closer data control and provide better service. All data will be routed through the central computer for analysis providing the combined service-research benefits originally intended. The Department will implement the research by issuing specifications providing for skid-resistant surfaces.

•ALTHOUGH the skidding problem, in one form or another, has prevailed for many years, its threat to human lives was not seriously considered until the advent of the automobile. Concurrent with its development, miles of hard-surfaced, high-speed highways were presented to the motorist for his pleasure and convenience. Although most of these roads have been improved or replaced to provide safer, faster highways in the form of divided and limited-access roads, many of the old roads still remain. Despite all the safety features built into present highways, more people are being killed annually than ever before. In Pennsylvania alone, 2131 traffic fatalities were recorded in 1967 while on the national scene, over 53,000 deaths were reported. The reasons are clear: more people are driving more cars more miles faster. The part that skidding plays in the latter observation is well documented in the literature (1, 2). The seriousness of the problem is emphasized, however, by the activities of private and public institutions in their efforts to resolve it.

INITIAL RESEARCH

The Pennsylvania Department of Highways was among the first to dedicate extensive funds to skid resistance research. In 1960, Pennsylvania State University was engaged to conduct a pilot program in one of the state's engineering districts that historically has had skidding problems (3).

The objectives of the testing program were to determine the degree of slipperiness as a guide for assigning priorities for resurfacing, and to gain insight into the causes of slipperiness. These objectives were met by utilizing the prototype single-wheel skid trailer designed and built by Penn State and the assistance of personnel from the Highway Department's Bureau of Materials, Testing and Research. Nineteen sites in District 10 were selected for testing. Eleven of these areas exhibited Skid Numbers well below 35 and were classified as slippery. Close analysis of these sites revealed the absence of sand-size particles in the polished pavement surface. Chemical analysis of the limestone from one of the slippery surfaces yielded less than an acceptable minimum fraction of silica sand required for adequate skid resistance. Surfaces exhibiting the greatest skid resistance showed sand-sized particles in the aggregate and a sandpaper-like appearance of the surface. The polishing effect of traffic was established by comparing the skid numbers in the wheel tracks with those in the center strips. From the results of these tests, recommendations were formulated for long- and short-range programs to improve the skid resistance of Commonwealth roads.

So encouraging was this experiment that a second one was planned for 1962. This time, the entire state was included for the purpose of establishing the suitability of the Penn State tester design for routine surveys and of initiating a continuing program of annual surveys of the highway system (4). The test schedule, prepared by the Department and covering a six-week period, included all 11 districts and the Pennsylvania Turnpike. The survey sites, selected by district personnel for known and suspected slipperiness, averaged about 23 projects per district. The skid resistance data showed that each district had its share of slippery pavements. The mean for all projects, excluding the Turnpike, was 34.4 at 35 mph while the equivalent figures for the Turnpike were 44.1 at 35 mph and 30.2 at 65 mph. The main surface types appeared not to affect the skid resistance significantly, whereas the aggregate had a pronounced effect on the readings obtained. Gravel surfaces exhibited the highest skid resistance whereas limestone pavements produced the lowest readings. Skid resistance, in general, was shown to decay with pavement age, rapidly at first and more gradually later on. The number of passes on the pavement surface, as computed from the average daily traffic (ADT), was actually found to be a more sensitive indicator of the decay of skid resistance than age alone.

THE JOINT ROAD FRICTION PROGRAM

In 1961, the Department initiated a cooperative research study known as the Joint Road Friction Program with Pennsylvania State University. The objectives of this ongoing study are to provide the Department with skid resistance measuring equipment and to conduct research into the fundamentals of skid resistance with the development of a scientific basis for controlling it. Since 1963, the Bureau of Public Roads has been a participating sponsor in this research.

An early report (5) deals with the development, selection, and performance of the single-wheel skid trailer. Whether for research purposes or for routine skid surveys, the following ten requirements are fundamental to the design of a skid trailer:

1. Meaningful measurements,
2. Precision of test data,
3. Minimum data processing,
4. Balanced coverage and test cycle frequency,
5. Adequate range of operation,
6. High degree of mobility and maneuverability,
7. Minimum traffic interference,
8. Ruggedness,
9. Economy of operation, and
10. Comfort and safety of crew.

The ability of a two-wheel trailer to measure skid resistance in either the left or right wheel track is of advantage in specialized experiments, but it is of little value for highway surveys or most research. Tests have shown that the Skid Number is the same in both wheel tracks of no-passing lanes, whereas the left wheel track exhibits lower readings where passing is permitted. Since highway engineers are generally interested in the lowest skid resistance of a section of pavement, a single-wheel trailer, so mounted that it normally runs in the left wheel track, is perfectly adequate. The pneumatic loading system of the single-wheel design permits changing the wheel load during operation and more importantly, it permits automatic and close control of the wheel load to a predetermined value. The pneumatic loading system also allows for raising the trailer wheel off the road for transportation between test sites. This is a definite advantage in some of the mountainous terrain in Pennsylvania.

In the course of research into the causes of slipperiness, various laboratory and field test equipment has been developed and constructed to measure specific factors which have a bearing on skid resistance. While some of this equipment has been described in various technical and research publications, the information is too scattered and incomplete to serve as a useful reference for workers in this field. One phase of this research program is embodied in a report which defines the test function, operating principle, specifications, and test procedure for laboratory and field skid test equipment (6).

Research was undertaken to evaluate the problem of wear and polish of highway pavements and their effect on the pavements' skid-resistance characteristics. A wear machine was developed which applied a controlled load against a pavement sample through a reciprocating rubber pad. The pavement samples consisted of aggregates glued to a metal holder by an epoxy cement. A mixture of water and abrasive was injected periodically between the surfaces in contact. Wear as such was not measured, but the polish produced by the wear was determined with the British pendulum tester. The general conclusion derived from the study was that the basic wear mechanism must be better understood and wear produced under conditions more closely resembling those on the highway must be studied before reliable results can be expected from the greatly accelerated wear which the reciprocating wear machine produced (7).

Other basic skid research conducted under this program which may be of interest, although not directly applicable to the scope of this paper, includes studies on the concept and use of the British portable tester (8), pavement wetting and skid resistance (9), pavement surface characteristics (10), and mineral wear in relation to pavement slipperiness (11).

THE SKID SURVEYS

Through an early phase of the Joint Road Friction Program, the Department was able to obtain its own single-wheel skid trailer in time to conduct a statewide annual skid survey in the fall of 1963. This, and all subsequent annual surveys through 1967 were conducted solely by the Department.

Responsibility for the selection of test sites is given to each of the 11 engineering districts in Pennsylvania. In the spring of each year the Department solicits from each district headquarters a list of 15 to 20 bituminous surface pavements where verification of slippery conditions is required. Most of the pavements thus listed are well-worn but many have only been in service a few years and some are new, so that the data are nearly representative of all type and ages of surfaces. It should be emphasized, however, that these pavements were listed because of a suspected slippery condition, so that, overall, the results may not truly reflect a cross-section of Pennsylvania's highways with respect to skid resistance.

The skid test crew begins testing as soon as the lists of pavements are received from the districts, which is usually in June or July. This is a departure from the original plan to confine testing to the fall season. Originally it was recommended by Penn State that the late fall was the best time to determine accurately the skid resistance of pavement, the reason being that this was the driest season and skid readings would be expected to be at their lowest. It was not expedient, however, for the Department to restrict thousands of miles of testing to a short, one- or two-month period in most areas of Pennsylvania. It was decided, therefore, to conduct year-round testing as weather permitted. The reasons were conscientiously considered: (a) other skid research programs were being given least priority and relegated to the "worst" testing season; (b) realistic skid readings for the high-volume summer traffic season could be recorded and compared from district to district as more years of data were gathered; and (c) seasonal effects on a pavement's skid resistance could be studied.

Survey data are returned to the individual district offices as each district's testing is completed, with recommendations for remedial action in specific cases. Some months later, a complete statewide survey report is prepared for the central office engineering staff. This report contains a compilation of data by district and an analysis and cumulative totals of all data to date. These annual reports have not been released, but some of the results are presented in this paper.

In completing the five annual surveys, the test crew logged nearly 25,000 miles, exclusive of other research, and averaged about 150 test projects per year. To accomplish this the test wheel has been dragged over the surface in a locked position for an estimated 500 miles. Considering all expenditures such as salaries, subsistence, and vehicle costs (including depreciation), it has been calculated that the average project costs $30.00 to test (based on 15 test cycles per project).

EQUIPMENT AND TEST PROCEDURE

The PDH Road Friction Trailer (Fig. 1) is an improved model of the original Penn State Road Friction Tester and was constructed under contract by the Mechanical Engineering Department of the University (5). The major change from the prototype, and now incorporated in it also, is the wheel force conversion system from a totally electrical system to a nearly totally hydraulic system whose response time is adequate (12).

During testing, the truck is operated at 40 mph for a distance adequate to appraise the whole pavement. The tester is designed to sample automatically, and at regular intervals, about 10 cycles per mile at 40 mph. The randomness of the locked-wheel intervals provides fair and adequate representation over the project. The skid number (defined as the friction coefficient of a tire skidding on a wet pavement times 100), as obtained from the left wheel path of the traffic lane, is recorded on a strip chart in the truck cab (Fig. 2).

A secondary field tool, known as the Penn State "drag tester" (13) (Fig. 3), accompanies the skid truck and is used in areas where the truck cannot operate safely. The operator merely samples the wetted pavement by pushing the tester at a normal walking speed of about two to three mph. The good to excellent correlation with a locked-wheel tester indicates the ability of the drag tester to serve as a substitute for a skid trailer whenever the latter cannot be used. The excellent correlation between the drag tester and the British pendulum tester indicates that the two devices are equivalent as far as the quality of test data is concerned (14).

Figure 1. PDH road friction tester.

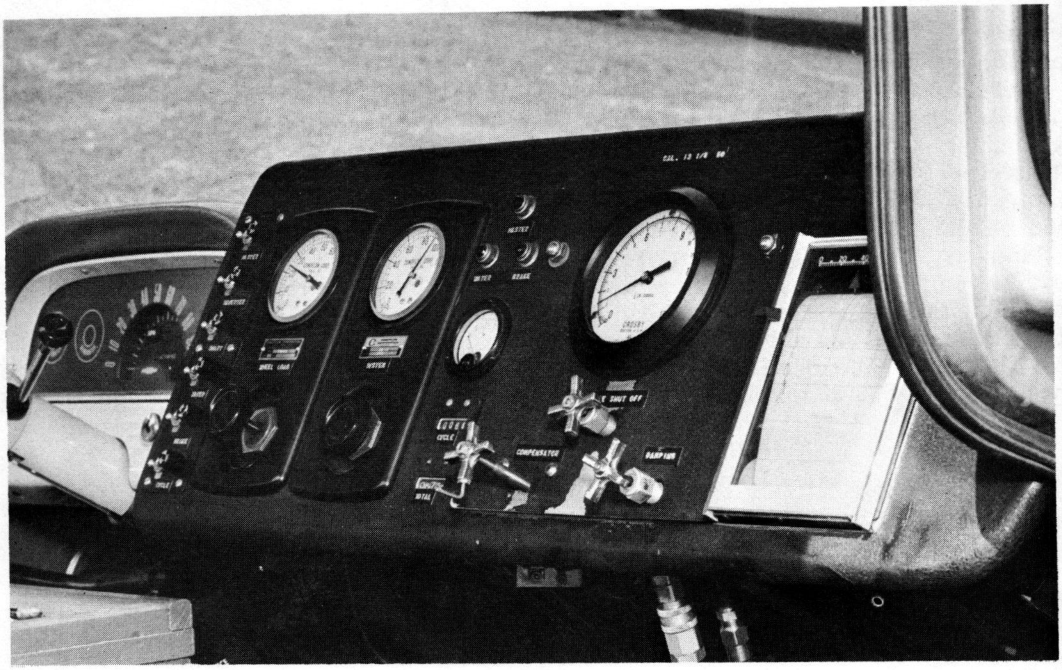

Figure 2. Instrumentation.

Figure 3. Drag tester.

SKID RESISTANCE SURVEY
FIELD RESEARCH DATA

L. ROUTE ____________ COUNTY

T. ROUTE ____________ DISTRICT ____________

STATIONS		TYPE	TYPE	AGGREGATE	EST.	YEAR	NO. PASSES	SKID READING	NO.		AIR	
START	FINISH	SURFACE	AGGREGATE	PRODUCER	ADT	PLACED	(x 1000)	(HI/LO AVG)	CYCLES	DATE	TEMP	REMARKS

(FRONT SIDE)

DATE	QUALITATIVE ANALYSIS														
	FI	MD	CO	OP	CL	SM	RO	PO	GR	FA	BL	PA	RI		

LEGEND:
- FI FINE-TEXTURED SURFACE
- MD MEDIUM-TEXTURED SURFACE
- CO COARSE-TEXTURED SURFACE
- OP OPEN-TEXTURED SURFACE
- CL CLOSED-TEXTURED SURFACE
- SM SMOOTH SURFACE
- RO ROUGH SURFACE
- PO POLISHED SURFACE
- GR GRITTY SURFACE
- FA FATTY SURFACE
- BL BLEEDING SURFACE
- PA PATCHED SURFACE
- RI RIPPLED SURFACE (WASHBOARD)
- SY SLIGHTLY
- PY PARTLY
- VY VERY

(REVERSE SIDE)

Figure 4. Field data sheet.

Pertinent field data are recorded on the skid survey form (Fig. 4). Surface temperature of the pavement, though not listed, is measured and recorded under "Remarks." Qualitative measurements are recorded on the reverse side of the sheet and include such parameters as roughness, polishing, openness, grittiness, harshness, fattiness, extent of bleeding, degree of patching, and rippling features. A one-through-three designation denotes progressively more of each parameter's presence. No comparative analyses of these parameters with the skid number have been made.

SURVEY RESULTS

An analysis, however, was made of the more obvious parameters such as aggregate type and surface type. The data indicate that aggregate type bears much influence in determining the skid resistance, whereas surface type has very little influence. These data are presented in the form of bar graphs which compare the aggregate type versus skid number (Fig. 5) and the surface type versus skid number (Fig. 6). The data are based on information gained from the skid surveys during the period from 1962 through 1967. The mix designations, characteristic to Pennsylvania, are identified as follows: ID-2 is a two-aggregate composition wherein the coarse aggregate passes the ½-in. sieve and the fine aggregate is a typical bituminous concrete sand passing the 3/8-in. sieve; FJ-1 is a sand-asphalt mix using the same bituminous sand gradation; FJ-3 is a sand-asphalt mix with synthetic rubber additive; FJ-4 is the same mix as the FJ-1 with an asbestos additive; S. T. designates a surface treatment, sometimes referred to as a chip seal.

Figures 5 and 6 were compiled from data collected on 773 separate roadway projects. The numbers in parentheses reflect the total number of projects tested in each category. In Figure 5, despite the variation in the average skid number between aggregate groups, the surface types within each group fluctuate but little. There is a pronounced degradation in skid resistance in descending order from gravel and sand down to limestone.

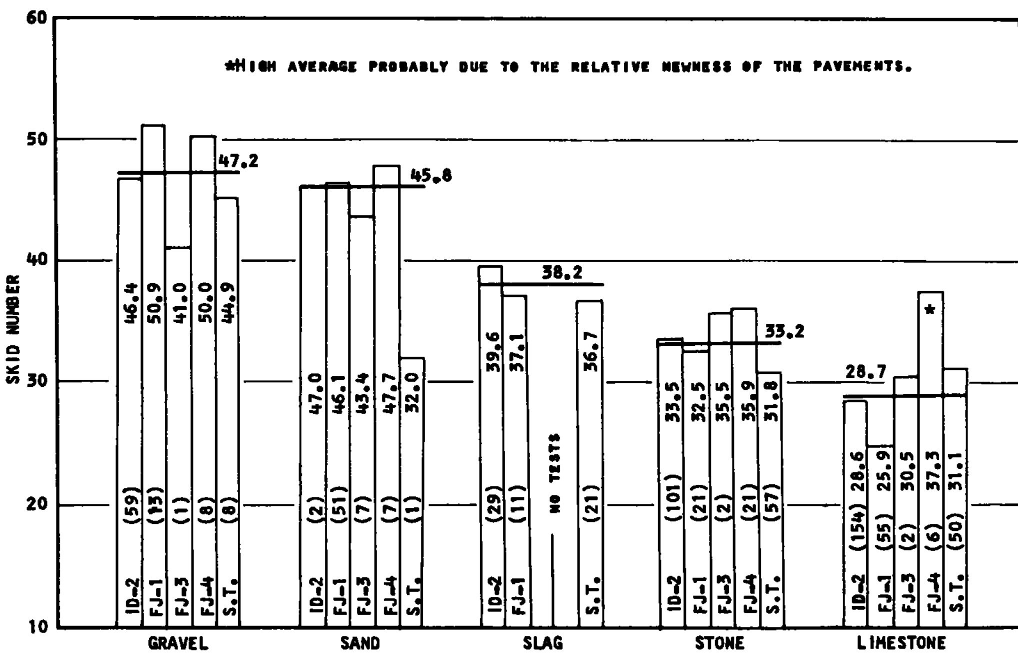

Figure 5. Effect of aggregate type on the skid number, values shown for various surface types are weighted averages for all tests recorded 1962-1967, numbers in parentheses represent the number of tests.

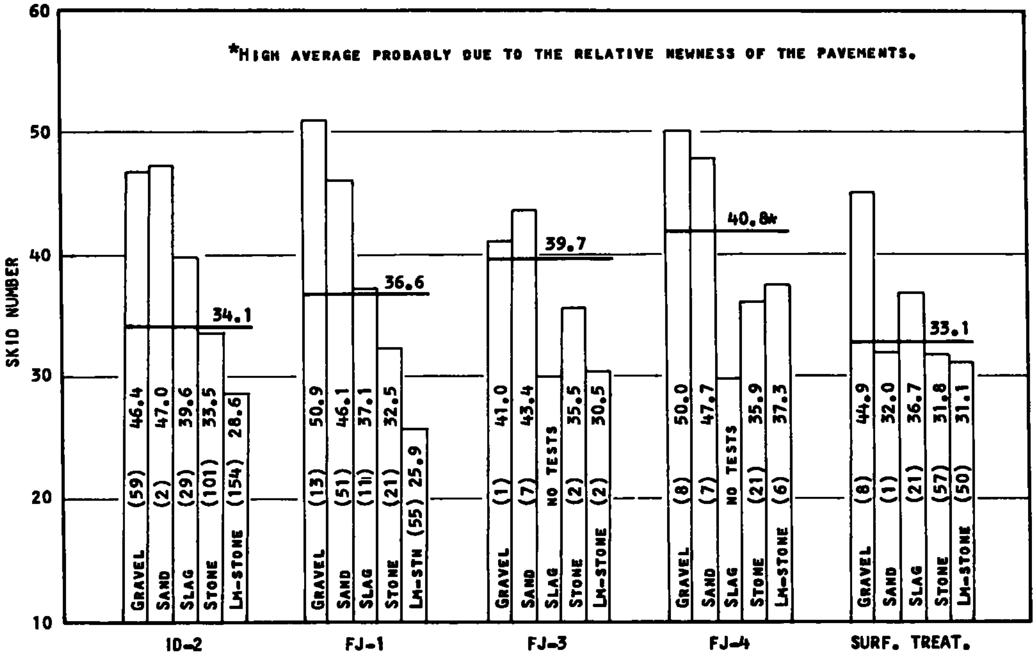

Figure 6. Effect of surface type on the skid number; values shown for various aggregate types are weighted averages for all tests recorded 1962-1967; numbers in parentheses represent the number of tests.

Conversely, in Figure 6 the average skid number of each surface type group varies little from one to another. However, within each group the variation is extreme, due to aggregate influence. The pattern follows the same descending order depicted by Figure 5. This information is not startling in terms of present knowledge but it confirms on a more substantial basis what has been suspected from previous but limited research. Although the data have been obtained from roadway surfaces suspected of slipperiness, and the results verify this, it is sincerely felt that these data could be projected validly to reflect a similar pattern if a random selection of pavements throughout the state were tested.

CURRENT PROGRAM

In-House Research—The Department is satisfied with the accomplishments of the surveys in that they have provided valid information regarding the skid resistance of various types of aggregates and surfaces and have served to establish and improve testing methods and techniques for research purposes. They have also made the districts aware of the importance and necessity of locating slippery pavements and taking the necessary corrective measures. These decisions have been based generally upon recommendations from the Bureau of Materials, Testing and Research and the acceptance of a minimum Skid Number of 40.

The next phase, pending delivery of another skid trailer, is to expand the skid survey program and inaugurate a full-scale, statewide roadway inventory. To expedite this, a third skid trailer will be acquired during fiscal 1968-69. The task will be tremendous, even if sampling techniques are employed, considering the more than 43,500 miles of highways on the state system. With three separate crews functioning, one truck will be assigned to purely research work while the others will perform service testing and road inventories.

The capability of the present road trailer will be increased considerably after installation of paper punch tape for data acquisition. A magnetic instrument tape recorder was not suitable for this vehicle, due to space and shock mounting requirements. Future vehicles will be equipped for total automatic data acquisition, however, including 7-channel magnetic instrument tape recorders. Automatic data processing equipment will be utilized to expedite data analysis. Provisions for data storage and recall have been initiated and should be functional in the near future. The use of portable skid measuring equipment in each district will be considered and the skid trailers may be assigned on a regional basis. The surveys will continue to provide the service function to the engineering districts as in the past; but because of more local assignment, the crews will be able to provide closer control of the data acquisition. At the same time, recording of all data on magnetic tape will permit the central research unit to process the input easily and promptly.

Experience gained while conducting the annual surveys has enabled the Department to undertake better-controlled research projects. An example of this is an aggregate blend study designed to show the influence of various amounts of skid-resistant aggregate in limestone mixes and evaluate the durability of bituminous mixes having various proportions of gravel. Recognizing that the supply of skid-resistant aggregates is critical in many areas of Pennsylvania, the Department initiated a field research project in an attempt to upgrade the skid resistance of local, polish-susceptible aggregates (15). The project was a surface-treatment-type application which included limestone, slag, and crushed and uncrushed gravel of several gradations. The slag and gravel sections produced skid numbers almost twice as large as the crushed limestone sections. An admixture of 25 percent by volume of slag and gravel to limestone surface increased the skid resistance slightly, but not enough to offset the inherent slipperiness of the principal aggregate component. Additional studies are being planned to evaluate further the effectiveness of blended aggregates.

Another research project is being conducted by the Department in one of the local engineering districts. The skid resistance histories of 45 new pavements are being kept to note their rate and pattern of deterioration. The program is designed to relate the effects of external variables such as temperature, season, and traffic to the numerous parameters of the road surface such as texture, aggregate and surface type, and asphalt content. Data are being collected on approximately 57 pavement sections. Of this total, 45 are tested on a monthly schedule while the remainder are tested annually or semiannually. Several of the special study groups such as the fine aggregate blend study are tested on a monthly schedule. The observations to date parallel the conclusions formulated previously from the skid surveys. Of particular interest are the specific decline curves for the particular aggregate combinations showing skid resistance degeneration over a period of time with traffic.

The need to record parameters other than those shown on the field survey data sheet has resulted from the annual survey. Accurately determined pavement characteristics (aggregate size distribution, aggregate mineralogy, cement concrete petrography, asphalt content, and others) are requisite to skid research, and a sampling program in conjunction with the testing has been initiated by the Department. The purpose of the program is twofold: first, to provide precise parameter determinations which relate to skid numbers; and second, to provide a means of perfecting a laboratory method for determining accurate skid-resistance levels of actual pavement surfaces. To accomplish this, the Department has assigned a core drill to the skid research unit and when expedient, all tested surfaces are cored, oriented, and carefully returned to the laboratory for skid testing with the British portable tester. A core holder (Fig. 7) has been devised to hold 4- and 6-in. cores in a level and properly oriented position and to provide an elevated stand for the British portable tester. A useful correlation between the British portable tester and the skid truck data, based on thousands of samples, should determine the feasibility of developing a British portable skid-resistance scale as a means of determining acceptability or rejection of a pavement.

Certainly, additional studies are urgently needed to determine the influence on skid resistance of such things as the chemicals placed onto a surface in the winter season, the effect of season and surface temperature, and the mineralogy and petrology of the aggregates themselves. The Department's petrographic laboratory is conducting a program to determine the relationship of skid resistance to the petrography of the

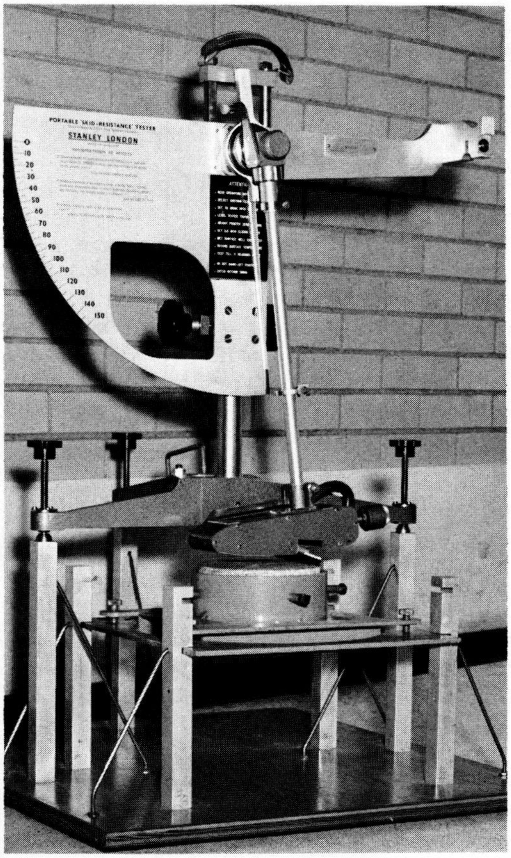

Figure 7. Core holder for RPT.

aggregates. For each general type of aggregate there is a wide range of skid resistance and the controlling aggregate parameters have not been clearly identified except in certain specific cases. At the present time there is no satisfactory construction or material specification to insure that a pavement surface will have adequate skid resistance after exposure to a considerable volume of traffic. The objective of this research program is to correlate the petrographic properties of aggregates used in roadway surfaces with the road friction tester skid measurements for those same sections of roadway. Further, it is hoped that a relationship can be established between the skid-resistant parameters of the aggregates and the identifiable stratigraphic units of both present and potential aggregate sources.

Continuing Sponsored Research—The Department will continue its sponsorship of the Joint Road Friction Program at Pennsylvania State University. The research is being directed under two phases: pavement slipperiness and pavement polishing. The objective of the former is to deepen the knowledge of the mechanism of friction between tire and pavement, and to employ this knowledge to develop guides for the construction and maintenance of pavement surfaces with improved frictional characteristics. Continued tests with the road friction tester will be concerned basically with a comparison of the ASTM tire with representative commercial tires. The research on the relation between pavement characteristics and tire-pavement friction will be continued, the most important phase of this effort being the investigation of aggregate shape effects. The measurement of pavement texture from a moving vehicle will be pursued further as will modifications of the road friction tester permitting it to operate in the slip mode.

The research on pavement polishing will investigate the polishing characteristics of selected aggregates and the effectiveness of roughening techniques. An attempt will be made to devise better methods of relating laboratory and field polishing data. A rotary wear machine has been constructed and work will continue on the study of aggregate polish with the use of roughening agents. A study will be undertaken to determine the best design for a polishing apparatus equally suitable for use in the laboratory and on the highway. The nature of the debris on the highway as it relates to polishing will receive further attention.

Implementation of Research—The research brought about by this program, together with the implications of the Federal Highway Safety Act, have created an immediate sense of awareness of the skid problem by the Department's top-level engineering staff. A directive from the Secretary of Highways to all engineering districts has advised them of the Department's intent to issue supplements to the Specifications providing for highly skid-resistant surfaces for both concrete and bituminous pavements. The program will be implemented in 1968 for projects under contract and will be extended in 1969 to cover surface treatments and wearing surfaces placed by the Department's maintenance forces.

The Bureau feels that the selection of an initial skid number and the enforcement of such specifications would be difficult. Current data on skid resistance are largely related to pavements which have been in service for some time. The histories compiled on road surfaces prior to traffic exposure are scarce. Limited data indicate that initial skid values are often high. The skid number can decrease by 40 percent in a few months when the aggregate is a polish-susceptible type.

Records have shown a wearing surface to read as high as 60 initially and later drop below the 40 Skid Number level. If a Skid Number specification were in effect, the Department could unintentionally accept a pavement that might later prove hazardous. If a high initial Skid Number is arbitrarily selected, certain wearing surfaces which may maintain a value of 40 or more for their service life, might not be able to qualify initially. Data indicate that these possibilities exist. Sufficient information to establish an initial Skid Number specification in Pennsylvania is not available at this time.

The Department is considering adoption of a supplement to the specification that would provide aggregate qualifications and the texturing of concrete rather than a Skid Number. The following recommendations are being considered:

1. Bituminous concrete:

   Fine Aggregate: Fine aggregate produced by the crushing of carbonate rocks shall not be used in bituminous wearing surfaces, but may be used in the base and binder courses.

   Coarse Aggregate: Aggregate prepared from carbonate rocks containing less than 25 percent siliceous particles shall not be used in bituminous pavement wearing surfaces but may be used in the base or binder courses and in the shoulder wearing surface. The siliceous particle content shall be determined by the Pennsylvania Department of Highways Test Procedure No. 203-68, Solubility Test for Aggregates.

2. Portland cement concrete:

   Fine Aggregate: Sand produced by crushing carbonate rocks shall not be used in concrete wearing surfaces.

   Final Finish Requirements: After the straightedge testing and surface corrections have been completed and just before the concrete becomes nonplastic, the surface shall be given a drag finish by dragging a seamless strip of damp burlap, cotton fabric or a wire brush longitudinally along the full width of pavement which shall produce a uniform surface of gritty texture. The texture produced shall have a minimum surface relief of 0.025 in. The texture of the surface shall be of uniform appearance and reasonably free from grooves over $\frac{1}{16}$-in. depth.

SUMMARY

The statewide annual survey was a wise choice in initiating a skid resistance research program in Pennsylvania. The Department has gained invaluable experience in technological know-how, as well as much knowledge with respect to the factors influencing skid resistance and pavement performance.

Aggregate type appears to be quite influential in contributing to skid resistance but the surface type into which the aggregate is mixed has little or no significance. Gravel and natural sand (quartziferous) aggregates produce pavements with more skid resistance than do limestone (calcareous) aggregates. Bituminous mixes made with some of the quartziferous aggregates, especially some of the gravels in Pennsylvania, create problems in other respects, however. Many of the flexible, gravel-aggregate pavements tend to ravel or lose aggregate.

The initial skid readings may be misleading if taken too soon. Asphalt coating of the aggregate definitely can influence its performance under the test wheel. Consequently, the Department is pursuing means to age samples of new pavement surfaces artificially in order to predict, by testing methods, the approximate level of skid resistance after a given number of passes, not yet determined.

The Department's pursuits in skid resistance research include many areas, but all contribute to the primary purpose, which is to provide a safer roadway on which to travel.

ACKNOWLEDGMENT

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Discussion

J. PAUL MARTIN and L. JOHN MINNICK, Technical Committee of the Pennsylvania Stone Producers Association—This discussion is presented because we believe, as members of a very important industry, that our thoughts and opinions should also be heard in this very vital matter. First of all, stone producers want to acknowledge that a problem does exist in many areas and we realize that aggregates are a part of this problem. As producers of aggregate we are also businessmen who wish to protect our industry from invalid or improper restrictions in use, especially since this industry is a vital segment of the economy of the country. We are interested in the development of realistic and meaningful aggregate specifications, but it is contended that the data presented by the authors do not warrant the extremely restrictive specification which they have suggested.

Pennsylvania is the leading producer of stone in the nation and has at the present time approximately 223 operating stone quarries and 115 sand and gravel pits. Most of this stone is supplied to the construction industry. Of all of the aggregate used in construction, approximately 75 percent represents stone. The type of stone varies from carbonate rocks, including calcitic limestone, magnesian limestone, and dolomite to siliceous materials such as diabase, sandstones, and gneiss. These aggregates have been used for many years in the construction of wearing courses on roads and considerable experience is available as to their performance in a variety of asphaltic and portland cement concrete mixtures.

The paper discusses the performance of some of these wearing courses in terms of the effect of both aggregate type and mix composition on the skid resistance properties of the pavement.

The data are based mainly on a series of statewide surveys which has been made on pavements that were "selected because of a suspected slippery condition." Each of these surveys has noted that this method of selection will give unrealistic or biased answers. Quoting from the 1965 Survey, "In most cases, only potentially slippery pavements were tested; therefore the average does not necessarily reflect a cross-section of the Commonwealth's highways" (16). From the 1966 Survey, "Since the Bureau specifically requested that the Districts submit a list of potentially slippery pavements. . ., the low, statewide skid average of 37 does not reflect an accurate cross-section of the Commonwealth's highways" (17). The 1967 Survey recognizes this problem and states further: "District and statewide averages would be unfair and in some cases meaningless, since the test projects submitted were, for the most part, subjectively selected" (18).

In spite of these observations the authors have, based on the self-same data, made numerous general conclusions pertaining to the effect of aggregate type and mix design on the skid resistance of bituminous pavements. They have stated: "Although the data have been obtained from roadway surfaces suspected of slipperiness, and the results verify this, it is sincerely felt that these data could be projected validly to reflect a similar pattern if a random selection of pavements throughout the state were tested" (19).

Thus, in spite of the fact that the individual surveys have each indicated that statewide averages are biased and in some cases meaningless, the authors have persisted in projecting general conclusions based on their feelings about these averages. The conclusions have been extended into a projection of overall performance of pavements that have not even been included in the survey at all. It is obvious that this type of extrapolation is totally unscientific and any accuracy of the conclusions obtained would be merely fortuitous, regardless of the number of tests involved in the study.

To illustrate the uncertainty of such an approach as utilized by the authors, the data available in the surveys have been statistically evaluated by computer and some of the results of this evaluation are presented.

Frequency of Testing

Based on the sampling plan which was used in the Pennsylvania Survey, the frequency of sampling with respect to mix or aggregate type serves as an indicator of the

TABLE 1

RATE OF TESTING

Mixture	ID-2	JA-1	FJ-1	FJ-2, 3, 4	FB-1, 2, 3
(a) Mixtures Placed					
Mixtures used in 1957-1966 (as percent of total bituminous concrete tonnage)	84.4	2.9	8.2	0.3	3.1
(b) Mixtures Tested					
Mixtures tested in 1962-1967 surveys (as percent of tests in Figure 6)	50.2	–	22.0	7.9	–
Mixtures tested in 1966 (as percent of tests in 1966 survey)	42.4	4.2	27.3	10.9	4.8
Mixtures tested in 1967 (as percent of tests in 1967 survey)	45.8	0.0	31.9	4.9	0.7

performance of a particular mix or aggregate. Any mix that performs well will be sampled infrequently, and conversely, any mix that does not perform well will be sampled more frequently than would be indicated by the amount of this material that was placed in service.

A review of the paper as well as the 1966 and 1967 Surveys shows that certain mixes are tested at a rate which is less than proportional to the amount of these mixes in service, indicating that these mixes are producing a disproportionately low number of slippery pavements (Table 1). ID-2 mixes are tested at a rate equal to about one-half of the rate at which they are placed, whereas FJ-2, 3, and 4 mixes are tested at 26 times the rate at which they are placed. This clearly indicates that, contrary to the authors' conclusions, mix design is extremely important as a factor in controlling skid res stance in Pennsylvania.

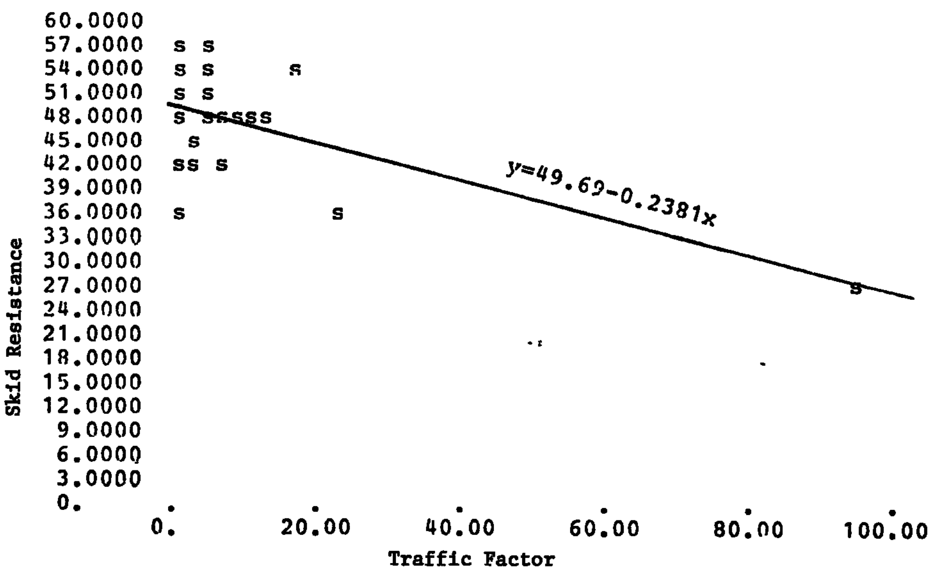

Figure 8. Pavements containing sand.

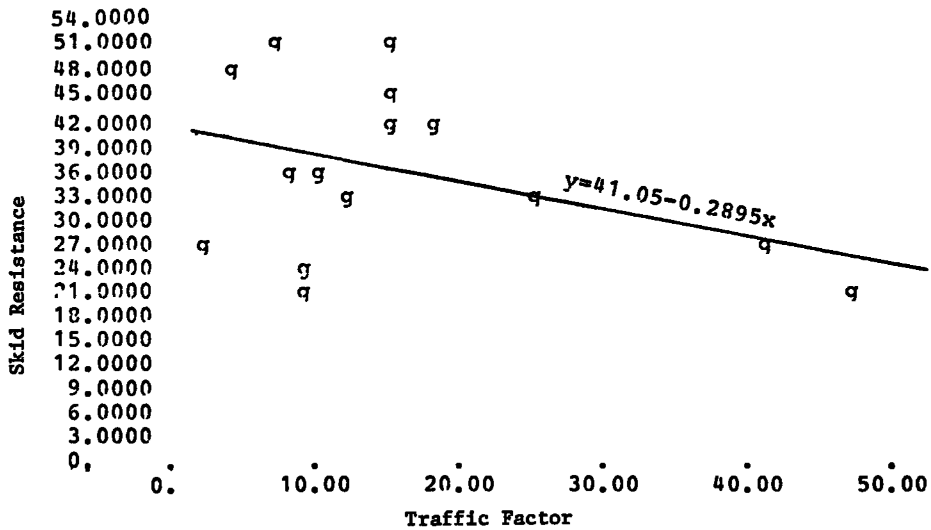

Figure 9. Pavements containing gravel.

Similar reasoning based on the amount of stone and limestone used and tested in Pennsylvania indicates that limestone may actually be performing better than sand and gravel. For example, in particular districts in the state where the majority of the pavements are made with dolomitic limestone, very little testing has been required; this indicates that these pavements are performing quite well. These results compare well with the report by Shupe and Lounsbury, which showed that dolomites exhibited up to 75 percent greater skid resistance than high calcium limestone (20). No attempt was made in the Pennsylvania surveys to differentiate between these two types of stone.

Rate of Polishing

Figures 8 through 11 present traffic profiles for the four types of aggregate referre to in the Pennsylvania Survey. The plots have been made by computer and regression lines (also calculated by computer) are added to the plots.

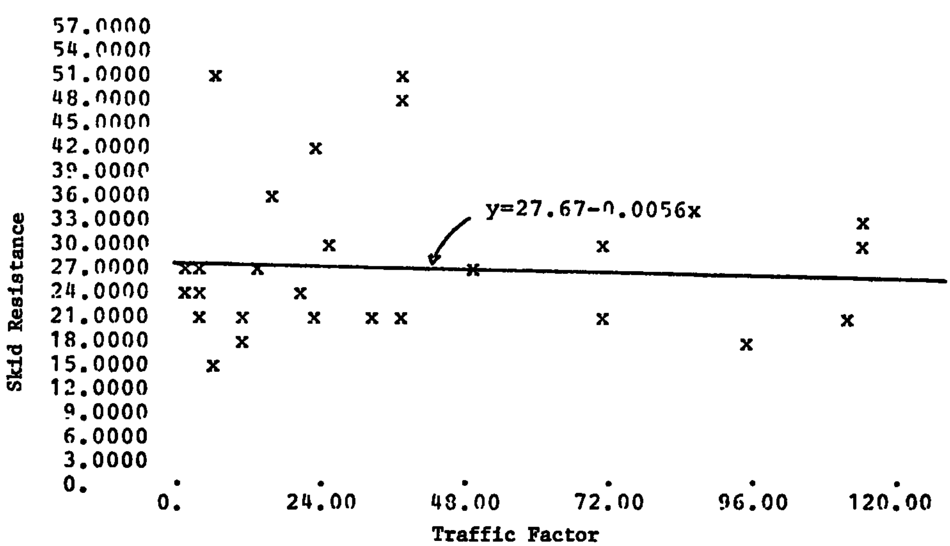

Figure 10. Pavements containing stone.

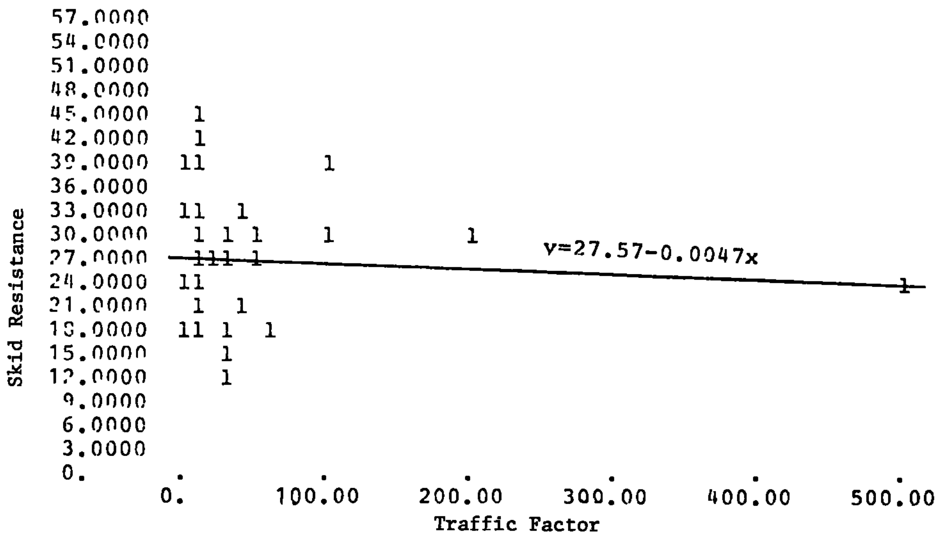

Figure 11. Pavements containing limestone.

These graphs indicate that stone and limestone are polishing only to a negligible degree, and that these materials will produce in service regardless of initial skid values pavements which are superior to those obtained with sand and gravel. Work in Michigan also observed that degradation in skid resistance occurred at a faster rate with gravel than it did with limestone (21).

Traffic Conditions

It should be noted that the stone and limestone were tested under traffic conditions which were three to four times as severe as those of sand and gravel in the 1967 Survey (Table 2). Also, in the 1966 Survey, similar differences occurred. The oldest gravel pavement tested was placed in 1954; the oldest limestone pavement was placed in 1932, and 6 limestone pavements were placed in the 1940's. It is significant that the limestone surfaces have remained in service for this length of time, whereas the gravel surfaces have presumably required resurfacing.

When the skid values which were obtained for each aggregate in the 1967 Survey are adjusted to the average traffic factor of the limestone pavements (Table 3), or to a traffic factor of 100, the skid values which are established for each aggretate show that limestone will perform as well as or better than sand and gravel in mature pavements.

These statistical evaluations of the Pennsylvania Surveys obviously present conclusions which are different than those submitted by the authors and thus clearly indicate the lack of validity of the conclusions.

As a further point of concern to the Pennsylvania stone producers, it is noted in the authors' presentation that the selection of test sites was developed each year in each of the engineering districts of Pennsylvania and that a list of 15 to 20 pavements were involved in each district. It is to be noted that there were exceptions to this plan and a number of the districts were not properly represented because there were not sufficient examples of slippery pavements to warrant an investigation. For example, the 1967 Survey includes only 4 sites in District 6.

The Pennsylvania stone producers have conducted tests using the Penn

TABLE 2

TRAFFIC CONDITIONS

Aggregate Type	Traffic Factor		
	Min.	Max.	Avg.
Sand	0 03	94 91	11 30
Gravel	1.16	45.57	14 75
Stone	0.68	113.40	33 01
Limestone	1 43	495.00	46 71

TABLE 3

ADJUSTED SKID VALUES

Aggregate Type	Skid Resistance of Pavements Tested in 1967 Survey	
	At Traffic Factor = 46.7	At Traffic Factor = 100
Sand	38.6	25.9
Gravel	27.5	12.1
Stone	27.4	27.1
Limestone	27.4	27.1

State drag tester in this same District on over 70 pavements; these are recognized as being pavements that are performing normally. They range from 1 to 10 years in age. The findings show many examples of pavements that are performing unusually well under high traffic conditions that utilize types of aggregate that are given poor ratings in the paper. For example, the skid values for ID-2 mixtures containing dolomite as the aggregate were among the highest for pavements that have been in service for more than 5 years.

These findings serve to emphasize again the invalidity that results from projecting the data of the Pennsylvania State Surveys into a prediction of the anti-skid performance of bituminous wearing surfaces in general. In view of this, it is unfortunate that the authors attempt to develop a blanket specification at this time, particularly since the Pennsylvania Highway Department has established a good research and field program that should give more realistic information in the near future. As an example, in the Department's current investigation, several interesting posibilities are being explored in connection with the use of aggregate blends and other changes in mix design which have indicated improved skid resistance characteristics.

Again, we wish to emphasize that we as a very vital industry do not want to find an unjustified all exclusive specification eliminating many quarries which are producing completely satisfactory pavements. It is our belief that blending operations are possible and have been used satisfactorily in other states. A joint task force of industry and Department of Highways' representatives is evaluating this and other avenues of approach at the present time.

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