TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle MANUAL - GUIDELINES FOR SKIDDING ACCIDENT REDUCTION		5. Report Date January, 1975 6. Performing Organization Code
7. Author(s) Ken Hankins		8. Performing Organization Report No. 1-10-70-135-5
9. Performing Organization Name and Address Texas Highway Department P. O. Box 5051 Austin, Texas 78763		10. Work Unit No. 11. Contract or Grant No. 1-10-70-135
12. Sponsoring Agency Name and Address Texas Highway Department P. O. Box 5051 Austin, Texas 78763		13. Type of Report and Period Covered Interim 14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U. S. Department of Transportation, Federal Highway Administration under the Study Title: "Definition of Relative Importance of Factors Affecting Vehicle Skids"

16. Abstract

This report was developed in response to the FHWA IM 21-2-73. The report contains guidelines for the following:

1. A Skid Resistance Inventory
2. A Systematic Procedure for the Identification and Correction of Hazardous Skid Prone Locations
3. An Evaluation of Current Pavement Design, Construction and Maintenance Practices to Provide Adequate Skid Resistance Properties for Needs of Traffic
4. An Annual Report for Skidding Accident Reduction

17. Key Words	18. Distribution Statement
Speed Gradient, Skid Resistance, Skid Resistance Inventory, Identifying Skid Prone Locations, Correcting Skid Prone Locations, British Wheel, Polish Value, Skid Resistance Performance	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-69)

MANUAL - GUIDELINES FOR SKIDDING ACCIDENT REDUCTION

By

Ken Hankins

Research Report 135-5

Research Study 1-10-70-135

Definition of Relative Importance of Factors
Affecting Vehicle Skids

conducted by

Planning & Research Division
Research Section
Texas Highway Department

In cooperation with the
U.S. Department of Transportation
Federal Highway Administration

January 1975

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

SUMMARY

This report was first prepared as a manual and as a direct response to IM 21-2-73, issued by FHWA. After studying IM 21-2-73, it was decided that the content of the Instructional Memorandum could be subdivided into four parts as follows:

1. A Skid Resistance Inventory
2. A Systematic Procedure for the identification and Correction of Hazardous Skid Prone Locations
3. An Evaluation of Current Pavement Design, Construction and Maintenance Practices to Provide Adequate Skid Resistance Properties for the Needs of Traffic
4. An Annual Report

This report offers guidelines directed toward each of the above four parts.

IMPLEMENTATION

In January, 1974, the FHWA Division Office began enforcing the last paragraph of IM 21-2-73. In other words, the Texas Highway Department began showing proof that a surface would provide lasting skid resistance qualities at the PS&E stage of design. After conferences between THD and FHWA, an Administrative Order was prepared by the Design Division outlining steps in using the British Wheel or of using skid resistance performance data to show adequate material properties for skid resistance. This report was revised to show the Polish Value requirements outlined in the Administrative Order, but a procedure for using skid resistance performance data as documentation has been shown herein.

In December, 1974, an Administrative Order prepared by the Maintenance Operations Division was issued which contained methods of identifying and correcting hazardous skid prone locations. The Administrative Order also, contained methods of reporting on the hazardous sites.

It is believed that IM 21-2-73, and therefore this report, has been implemented with the exception of the skid resistance inventory portion. Guidelines for obtaining a skid resistance inventory are included herein.

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GUIDELINES FOR SKIDDING ACCIDENT REDUCTION

BACKGROUND

Highway Safety Program Standard 12, issued by the Secretary of Transportation June 27, 1967, indicates that every State shall have a program of highway design, construction and maintenance to improve highway safety. Later, on May 3, 1972, the Federal Highway Administration issued PPM 21-16. This PPM called for among other things a traffic records system which correlates accident experience with highway data. IM 21-2-73 dated July 19, 1973 provided basic guidelines for a Skid Accident Reduction Program. A copy of IM 21-2-73 is included in the appendix for additional information. In response to the above information a guideline for use in Texas follows. This guideline consists of four items which are:

Chapter 1. Skid Resistance Inventory.

Chapter 2. A Systematic Procedure for the Identification and Correction of Hazardous Skid Prone Locations.

Chapter 3. An Evaluation of Current Pavement Design, Construction and Maintenance Practices to provide Adequate Skid Resistance Properties for the Needs of Traffic.

Chapter 4. Annual Report.

The intent of this guideline is (1) to establish a systematic procedure for finding and correcting (skidding) accident prone sites and (2) to insure an adequate, long lasting skid resistant surface where surface construction is employed.

Chapter 1. Skid Resistance Inventory

Skid Test Units are available for inventory purposes and are located in District 5 (Lubbock), 10 (Tyler) and 15 (San Antonio). A statewide inventory of skid resistance measurements is to be established and in operation by December 31, 1975. Training programs for Test Unit operation and data collection have been offered to each District. However, information as to scheduling and operation is in the System Skid-R Manual available from D-10. Approximately 150 to 200 miles may be tested per day at a cost of about $1.25 per skid lane mile. Data processing and report preparation are an additional cost of $0.96 per skid lane mile with a total cost of $2.21 per skid lane mile. It is recommended that standard measurements be obtained at 40 mph using the following table as a minimum time schedule.

TABLE I SUGGESTED INVENTORY PERIODS

Highway Class	ADT (each traveled lane)	
	Less than 250	250 Or Greater
IH	Once per year	Once per year
US	Once per 2 years	Once per year
SH, Loops and Spurs	Once per 3 years	Once per year
FM & Park Roads	Once per 3 years	Once per year

Skid resistance values may be expected to be lower at higher speeds and since measurements are to be made at 40 mph, the following information may be used to predict the skid resistance at speeds greater than 40 mph.

TABLE II SPEED GRADIENTS FOR SEVERAL PAVEMENT TYPES

Pavement Type	Speed Gradient
Seals or Surface Treatments in good condition	0.1 SN/MPH
Asphaltic Concrete (Usual)	0.2 SN/MPH
Flushed Seals or Surface Treatments, Consolidated Asphaltic Concrete and new Portland Cement Concrete with Burlap Drag	0.25 SN/MPH
Polished Portland Cement Concrete	0.3 SN/MPH

The loss of skid resistance (that is SN or Skid Number) per unit of increased speed is known as the speed gradient. An example using the above information would be:

Assume the Skid Number at 40 mph is 47 which was measured on an asphaltic concrete pavement in good condition. It is desired to determine the Skid Number at 60 mph.

$$SN_{60} = SN_{40} - (0.2 \text{ X Speed Differential}) = 47 - (0.2 \times 20) = 43$$

Actually,the information in Table II is very general in nature and should be used for ranking pavements in the Correction portion of A Systematic Procedure for the Identification and Correction of a Hazardous Skid Prone Locations chapter which follows. No attempt should be made to use Table II in predicting the friction available to a driver in natural rainfall conditions. For further information on speed gradient consult the appendix.

Chapter 2. A Systematic Procedure For The Identification and Correction of Hazardous Skid Prone Locations.

Identification: Skidding accidents usually occur on wet pavement. However, it is not easy to define a skidding accident and present accident reports do not always indicate the situation in which a vehicle skids or more particularly where "control-loss" occurred in the accident event. But, it is possible to study the accident records and determine those locations which have unusually high accident occurrances. Therefore, the following criteria is recommended in the selection of these locations.

HAZARDOUS SKID PRONE LOCATIONS

A. For Spot Locations

Any one tenth (0.10) mile section exhibiting 3 or more wet weather accidents in a one year period.

B. For Long Sections

(1) Any Control-Section exhibiting 2 or less wet weather accidents annually should not be considered.

(2) All Control-Sections exhibiting 20 or more wet weather accidents annually should be considered without restriction.

(3) For Control-Sections having 3 to 19 wet weather accidents annually the Control Section should be considered if:

a. $\frac{DVM}{WWA} \leq 3000$

Where DVM = daily vehicle miles

WWA = number of wet weather accidents and

b. The Control-Section length is three tenths (0.30) Mile or more.

Correction Procedures: Each highway accident location is unique and correction procedures are difficult to determine without a full study by a trained traffic Engineer. However, the following recommendations are offered as minimum guidelines for corrective action:

A. Where the Skid Number is found to be less than that number determined by the procedure given in IM 21-2-73 attachment, August 1, 1973, "Guide for the Evaluation of Current Pavement Practices to Attain Skid Resistant Qualities", Page4, 3rd paragraph (or see NCHRP Report 37), signs denoting the pavement slippery when wet shall be placed in an appropriate manner.

B. Where the Skid Number is found to be less than that number determined by the procedure given in IM 21-2-73 attachment (See A) above and the highway area meets the criteria of a Hazardous Skid Prone Location, signs denoting the pavement slippery when wet shall be placed as soon as possible and remedial surface treatment to assure improved skid resistance shall be placed as soon as possible. On occasions in which remedial treatment cannot be accomplished with available maintenance funds, a request for authorization and finance for a contract construction job should be submitted. Upon approval, the usual plan preparation procedure should be followed. Where plans for reconstruction of the surface are in preparation prior to the time the highway area is noted as hazardous, these plans shall be considered sufficient preparation for corrective action.

Chapter 3. An Evaluation of Current Pavement Design, Construction and Maintenance Practices to Insure Adequate Skid Resistance Properties for the Needs of Traffic

The following recommendations are made as guidelines for minimum requirements for pavement surfaces in the "B" portion of "Corrections" in Chapter 2 above or in surfaces which are required by the Federal Highway Administration to have sufficient skid resistant properties.

Flexible Pavements

Including: 1) Seals or Surface Treatments, 2) Asphaltic Concretes, 3) Plant Mix Seals, 4) Slurry Seals, and 5) the Cover Stone used in Sprinkle Treatments. These pavement types shall all meet either (A) the Laboratory Tests or (B) the Field Performance Tests:

A. Laboratory Tests

Minimum Polish Value for Coarse Aggregate	Present ADT Grouping
None	0-749
30	750-1999
33	2000-4999
35	5000-Over
35	All Interstate Highways

OR

B. Field Performance Tests

The "Vehicle Passes Per Lane" should be calculated for the expected structural life of the highway portion to be treated. If the structural life can not be predicted, it is suggested that five years be used as a basis for calulation.

The coarse aggregate of a given source is considered acceptable if the "Vehicle Passes per Lane", expected during the structural life of the surface to be placed, yields an acceptable SN_{40} value when compared with the skid resistance performance curve.

A skid resistance performance curve may be obtained by the following:

1. Obtain the skid number and the "Vehicle Passes Per Lane" at the time past skid testing was performed for any surface type in which a particular source of material was used.
2. Obtain the logarithmic value for the SN_{40} and for the "Vehicle Passes Per Lane" for each periodic test above.
3. Plot the values on arithmetic paper similar to the sample shown on page 10.
4. At least six periodic tests must have been performed (at least six plot points): the total range of values for the "Vehicle Passes Per Lane" must be at least 250,000; and one of the measurements must have been measured after at least 750,000 "Vehicle Passes Per Lane". The six periodic tests are a minimum number. Since the intent of Field Performance Tests is to establish the average rate of polish for <u>a given source and pavement type</u>, a large number of periodic tests should be used if the data is available. Thirty randomly selected plot points are generally considered sufficient to indicate trends.

5. After plotting the values, a mean linear line should be fit through the plot points. This may be done visually but particular attention should be made to fit the line midway between SN_{40} points (vertically).

The determination as to the acceptability of a source may be determined as follows:

1. The expected "Vehicle Passes Per Lane" for the structural life of the highway portion to be treated (mentioned in the first paragraph of "B Field Performance Tests) should be found on the horizontal axis of the plot and a line drawn vertically to intersect the mean linear line established in "5" above. From this intersection point a horizontal line may be drawn to intersect the vertical axis and the logarithum of the SN_{40} value found at the intersection point. The antilogarithum of the SN_{40} at the intersection point is then found and analyzed to determine if the source is acceptable.
2. The source is considered acceptable for use if the SN_{40} value at the intersection point is greater than that found in IM 21-2-73 attachment, August 1, 1973, "Guide for the Evaluation of Current Pavement Practices to Attain Skid Resistant Qualities", Page 4, Paragraph 3 - for 40 mph.
3. Documentation of an acceptable source by Field Performance Tests should be similar to the attached "Record of Field Performance Skid Resistance" Sample following.

Figure 1

RECORD OF FIELD PERFORMANCE
FOR SKID RESISTANCE

District_____ Date______________ Surfacing to Occur on Hwy No.________________

County_______________ Control______ Sec._______ Job______ Fed. Proj. No.____

A. Materials Source Being Analyzed:

Source Name:____

Location:____

____

B. Skid Resistance Information

SURFACE TYPE________________

Location of Section Tested	Test Date	SN_{40}	Traffic Per Lane	Log SN_{40}	Log of Traffic Per Lane

C. Calculations

Total Vehicle Passes per Lane in the Expected Structural Life of the Highway to be Treated (TVPPL)

1. Estimated Years of Service (EYS) = ________________
2. Present ADT (PADT) = ________________
3. Future ADT at the End of the Structural Life (FADT) = ________________
4. Percent Distribution of Traffic for Most Heavily Traveled Lane (PDT) = ________________

$$TVPPL = EYS(365)\left(\frac{PADT+FADT}{2}\right)(PDT)$$

TVPPL = ________________

Log TVPPL = ____________

Skid Resistance at Expected Structural Life Log SN_{40} at Intersection Point (See attached plot) = ________________

Antilog of SN_{40} at the Intersection Point (or SN_{40} at the End of the Expected Structural Life) = ________________

Figure 2 (Example)

RECORD OF FIELD PERFORMANCE
FOR SKID RESISTANCE

District 30 Date 6/6/74 Surfacing to Occur on Hwy No. IH-100

County ZEK • Control 40 Sec. 38 Job 37 Fed. Proj. No. F-40(2)

A. Materials Source Being Analyzed:

Source Name: J and Q Materials

Location: Lob County - West of US-999 and 10 miles South of Lob, Texas

B. Skid Resistance Information

SURFACE TYPE HMAC

Location of Section Tested	Test Date	SN_{40}	Traffic Per Lane	Log SN_{40}	Log of Traffic Per Lane
US-14 from FM-12 to KCRR	5/74	50	1500	1.70	3.18
US-14 from FM-10 to FM-12	5/74	39	2200	1.59	3.34
FM-3 from US-2 to US-5	5/74	37	16,000	1.57	4.20
SH-8 from SH-19 to Joe Cr.	5/74	48	33,200	1.69	4.52
SH-8 from Joe Cr. to KCRR	6/73	43	44,700	1.63	4.65
FM-10 from SH-3 to US-14	6/73	40	74,200	1.60	4.87
IH-2 from Joe Cr. to FM-11	6/73	47	631,000	1.67	5.80
IH-2 from FM-4 to SH-2	6/73	29	2,630,000	1.46	6.42

C. Calculations

Total Vehicle Passes per Lane in the Expected Structural Life of the Highway to be Treated (TVPPL)

1. Estimated Years of Service (EYS) = 5
2. Present ADT (PADT) = 1300
3. Future ADT at the End of the Structural Life (FADT) = 1700
4. Percent Distribution of Traffic for Most Heavily Traveled Lane (PDT) = 50 %

$$TVPPL = EYS(365)\left(\frac{PADT+FADT}{2}\right)(PDT)$$ TVPPL = 1,368,750

Log TVPPL = 6.136

Skid Resistance at Expected Structural Life Log SN_{40} at Intersection Point (See attached plot) = 1.57

Antilog of SN_{40} at the Intersection Point (or SN_{40} at the End of the Expected Structural Life) = 37

EXAMPLE
FIELD PERFORMCE DATA SAMPLE
COARSE AGGREGATE MATERIALS SOURCE-J.&Q. MATERIALS-LOB COUNTY
PAVEMENT TYPE-TYPE D-HMAC

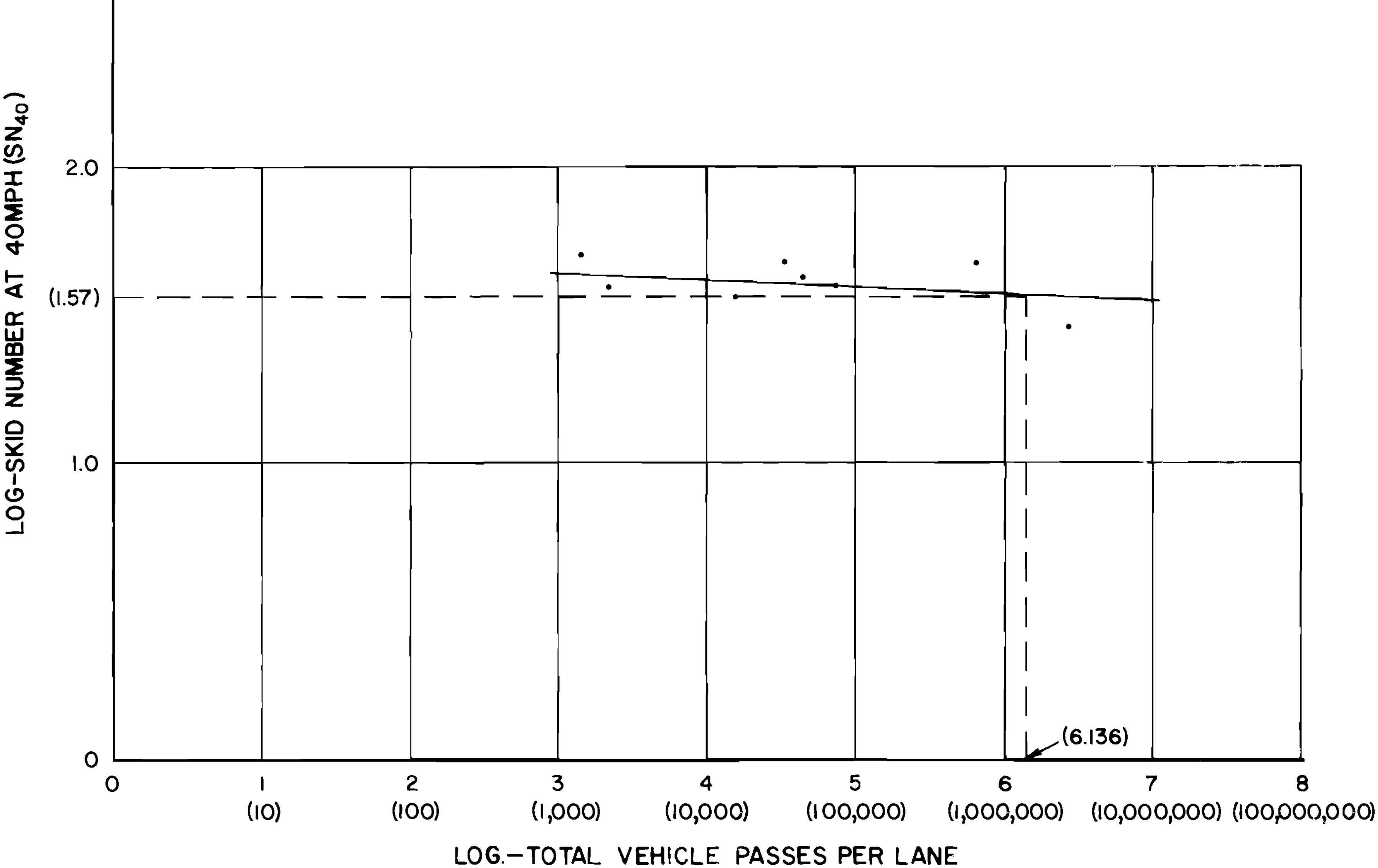

Figure 3

Rigid Pavements

The existing specifications adequately cover the requirements for obtaining skid resistant surfaces on Portland Cement Concrete pavements. Rigid pavement shall meet the following items occurring in the Standard Specifications.

A. Laboratory Tests

Minimum Insoluble Residue Value for Fine Aggregate	Minimum Texture in Inches from Sand Patch Test
28%	0.025 - Pavements
	0.035 - Bridge Decks

Chapter 4. Annual Report

A report of the highway safety improvement program is required annually. A part of this report is the skid accident reduction program. Of basic interest in the annual report for the skid accident reduction program is skid prone sites and the efficiency of treatment. The Field Safety Review Team in each District should submit its report to the Chairman of the Highway Traffic Safety Section for consolidation and further submission. The District report should be delivered about November of each year and should be based on the previous years data.

Report Type 1 and Report Type 2 attached should be used in reporting. Report Type 1 will consist of a single page annually. The report consists of District identification and a summary of the number of locations for both spot and control sections. Since the accident report file for a given year is not completed until about September of the following year the "Current Year" noted in the report(s) will concern the year ending about nine months earlier. For example, the compiling of the accident information for the "Current Year" 1973 will not be completed and available until around September, 1974. Therefore, the annual report for the "Current Year" 1973 would be submitted around November, 1974.

Report Type 2 should be submitted with report Type 1 but will concern the locations in which corrective action was initiated one year prior to the "Current Year". In this manner the accident information at least one year before treatment and the accident information at least one year after treatment can be revealed.

One sheet of Report Type 2 should be submitted for each location.

For example, assuming a "Current Year" 1973 where corrective action was initiated at a location in February, 1972 the "before treatment" accident information should consist of:

data between January 1, 1971 to December 31, 1971
January 1, 1972 to treatment date February 1972.

After treatment information should consist of:

data between Treatment date February, 1972 to December 31, 1972
January 1, 1973 to December 31, 1973.

Since exact location is not of interest, the locations for any given year should be numbered in consecutive order. The full location number would be:

District Number - Year Treatment Imposed - Consecutive No.

A brief description of corrective action may include items such as signing, seal course placed, asphaltic concrete overlay placed, superelevation improved, etc. Or, corrective action may include several items. If the surface was improved, the before and after skid numbers would be of interest.

On many control-sections the entire length may not require corrective action. In any event, an estimate of the percentage of length treated would be of interest. If the information is available, an estimate of the cost of treatment would be helpful in an analysis for future action.

Figure 4

Annual Report

of the

Skid Accident Reduction Program

for

District No.__________

District Location____________________

for

Current Year 19_____

Yearly Summary

Number of hazardous spot locations selected by the computer = _______.

Number of spot locations considered hazardous after analysis = ______.

Number of spot locations considered hazardous for which corrective procedures have been established = __________________.

Number of hazardous Control Sections selected by the computer = _____.

Number of Control Sections considered hazardous after analysis = ____.

Number of Control Sections considered hazardous for which corrective procedures have been established = __________________.

Comments:

Figure 5

Report

for

Locations Considered Hazardous

Two Years Prior to Current Year

Current Year is 19____

Location Number______________ Spot or Control Section (Circle Appropriate Site Type)

Number of Wet Pavement Accidents Before Treatment

Between______________, 19_____ and ______________, 19_____ = _____

Between______________, 19_____ and ______________, 19_____ = _____

Total No. _____

Number of Wet Pavement Accidents After Treatment

Between______________, 19_____ and ______________, 19_____ = _____

Between______________, 19_____ and ______________, 19_____ = _____

Total No. _____

Brief Description of Corrective Action:

For Control Sections state approximate percent of length treated:

Comments:

APPENDIX A

IM 21-2-73

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
WASHINGTON, D.C. 20590

INSTRUCTIONAL MEMORANDUM 21-2-73 July 19, 1973
HNG-23

SUBJECT: Skid Accident Reduction Program

SUPERSEDES: Instructional Memorandum 21-3-68 dated April 29, 1968

Pavement skid resistance is one of many elements that need to be recognized in providing a safe highway. It is of sufficient importance that all practical measures should be taken to insure that pavement surfaces are constructed and maintained with the best skid resistance properties that can feasibly be provided and that sections of pavement with inadequate skid resistance properties be identified and corrected.

Highway Safety Program Standard 12, issued by the Secretary of Transportation June 27, 1967, states that every State shall have a program of highway design, construction and maintenance to improve highway safety. This program shall provide that: "(D.) There are standards for pavement design and construction with specific provisions for high skid resistance qualities, and (E.) There is a program for resurfacing or other surface treatment with emphasis on correction of locations or sections of streets and highways with low skid resistance and high or potentially high accident rates susceptible to reduction by providing improved surfaces." In response to this standard, each State is expected to develop a program to reflect the individual needs and conditions of the State, but as minimum shall include:

1. An evaluation of current pavement design, construction and maintenance practices to insure that the skid resistance properties are suitable for the needs of traffic.

2. A systematic procedure for the identification and correction of hazardous skid prone locations.

The skid resistance evaluation for bituminous pavements is to include a determination that the aggregate used in the top layer of future pavements is capable of providing adequate skid resistance properties, when incorporated in the particular mix and that the mix is capable of providing sufficient stability to insure the durability of the skid resistance. The evaluation for PCC pavements is to include a determination that the finishing procedures, mix design and aggregate provide the initial texture and necessary surface durability to insure

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adequate skid resistance. Materials and designs resulting in surfaces which have proven to be nondurable with inadequate skid resistance properties are not to be approved for Federal-aid projects. A guide for the evaluation of pavement design, construction and maintenance practices is attached.

PPM 21-16, Highway Safety Improvement Program, May 3, 1972, calls for among other things a traffic records system which correlates accident experience with highway data. These data, along with a special review of wet weather accidents and the measurement of pavement frictional characteristics at particular locations, should be used in determining the locations of skid prone locations and needed corrective work.

Skid Resistance Measurement

In order to fully understand and evaluate current pavement design and to establish a logical program for the correction of skid prone locations, it is essential that each State have a program of making skid resistance measurements. Sufficient measurement data should be available to enable the designer to accurately predict the skid resistance performance of a given pavement mix design utilizing a particular aggregate or aggregates and constructed according to an accepted procedure.

A statewide inventory of skid resistance measurements is called for by the National Emphasis Program of the Highway Safety Program Management Guide issued by the Federal Highway Administration. This inventory is to be established and in operation by December 31, 1975.

The initial determinations of skid numbers and skid resistance speed gradients, as described in the attachment, should be made on a selected sample of surface representative of the various combinations of mix designs, aggregates and construction procedures for pavements which have been exposed to sufficient traffic to allow an appraisal of the skid resistance performance. This information can then be used to estimate the condition of the remaining pavement for similar conditions of surfacing and traffic, and to determine probable critical locations. Additional skid measurement efforts should then be directed toward those found deficient in the initial determination described above. These determinations should be completed as an early part of the above indicated inventory work. Pavement surfaces should be tested with a skid trailer following procedures outlined in ASTM E274-70"Standard Method of Test for Skid Resistance of Paved Surfaces Using a Full Scale Tire" or with an equivalent device which will give comparable results.

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Corrective Measures

A location in need of a thorough engineering evaluation for corrective action may be identified by a high frequency of wet weather accidents, by a low skid number, or by a combination of the two. Once the location is identified, an examination of the overall geometric conditions in the vicinity of the accidents is in order. Study should be given to the alignments, signing, grades, drainage, cross section and superelevation, skid resistance, obstacles, traffic volume, percentage of time the pavement is wet, and the likelihood of sudden vehicular maneuvers. Such a study will reveal deficiencies in the areas and suggest appropriate corrective work.

Each State should set up general guidelines based on their specific conditions for the identification of highway sections on which a thorough engineering evaluation will be made. Such guides should reflect the total pavement skid conditions within that State, including the available skid resistance data and measurement methods, and a practical skid resistance level that will indicate those sections with priority needs for inclusion in an early corrective program.

Federal-aid Fund Participation

The costs to provide new or reconstructed pavements with desirable skid resistance qualities are eligible items for Federal-aid funds as applicable for the system concerned.

Federal-aid participation in work that is justified only by skid resistance measurements will be limited to corrective treatment of the pavement surface. This work may consist of grooving portland cement concrete or the addition of a thin overlay (less than 1-1/2 inches in thickness) of bituminous material specifically designed to provide the desired skid resistance qualities. The addition of minor modifications to the pavement cross section, such as corrections of deficient superelevation may be included. Work involving more extensive modifications than noted above will follow the procedures outlined in paragraph 4a of PPM 21-16.

To be eligible for Federal-aid, the linear extent of corrective work should not be less than 500 feet on any lane or pavement, except that such work may be of less length at intersections of crossing highways or streets. Work on pavements of crossing highways and streets that are not a part of a Federal-aid system may be included as a part of the Federal-aid project for a distance not to exceed 50 feet beyond the right-of-way of the Federal-aid highway.

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Program Reports

In accordance with paragraph 6 of PPM 21-16, each State is to annually evaluate its highway safety improvement program and provide copies of a summary report to the Federal Highway Administration. The progress and the status of the States' skid accident reduction program on all Federal-aid system highways should be clearly indicated.

The division engineer is expected to monitor the States' skid resistance improvement program on a continuing basis, reviewing it for reasonableness and seeing that it is implemented at the earliest possible date. The division engineer must be assured that all future PS&E's involving surface courses will provide for the objectives included in this memorandum.

Norbert T. Tiemann
Federal Highway Administrator

Attachment

GUIDE FOR THE EVALUATION OF CURRENT PAVEMENT PRACTICES TO ATTAIN SKID RESISTANT QUALITIES

Skid Resistance Elements

A desirable surface, from the safety standpoint, is one which: (a) develops a large amount of friction between the tire and pavement, (b) has sufficient surface voids to prevent buildup of water pressure at the tire-pavement interface at the speed of traffic, and (c) is capable of retaining these properties under traffic and environmental conditions throughout the life of the surface. The size, shape, and arrangement of particles on the surface as well as the surface characteristics of the individual particles control skid resistance qualities. Therefore, material properties, mix design and construction techniques are all critical to the development of a good skid resistant surface.

Pavement mix designs and surface finishes, for both new construction and resurfacing, should be such as to provide a sufficiently high level of initial skid resistance to insure adequate skid resistance properties at the end of the life of the surfacing, allowing for loss in skid resistance from traffic and anticipated loss of voids from consolidation or wear.

High traffic volumes and the occurrence of high percentages of wet weather time increase the probability of accidents involving skidding and hence justify additional costs to insure the provision and retention of high skid resistance properties. Only polish resistant aggregates capable of maintaining high skid resistance under heavy traffic volumes, and mix designs and finishing procedures which produce adequate texture initially and are capable of resisting consolidation and wear should be used for high volume roads.

Roads serving low speed traffic (operating speed less than 40 mph) on which there are frequent stops and severe cornering maneuvers, require a high level of friction at low speeds. High skid resistance at high speed is not so important on these roads. High speed conditions require the availability of adequate friction at high speed for necessary maneuvers. A surface may provide adequate friction at low speeds, yet be inadequate for high speed conditions. Pavement surfaces, therefore, should be designed on the basis of the properties measured at the expected operating speeds. Generally, surfaces which provide adequate friction for high speed conditions will also be adequate for low speed operations.

Adequate skid resistance properties for high speed traffic conditions require both the provision of adequate friction and the provision of adequate drainage channels between the tire and pavement surface or

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into the pavement surface under the tire imprint, to prevent the buildup of excessive water pressure at high speed. This drainage potential is recognized as a necessary property for adequate skid resistance at high speed. The subject is discussed in considerable detail in NCHRP Report 37, "Tentative Skid Resistance Requirements for Main Rural Highways," quoted as follows:

> "The realization that the slip and skid resistance level of any one pavement surface is characterized by two, and obviously independent, surface properties, is of great importance to the pavement designer, the tester operator, and the maintenance personnel. It cannot be overemphasized that a high pavement friction potential (produced by a gritty or sandpaper-like texture) is a necessary--and for speeds below, say, 40 mph a sufficient--condition for adequate slip and skid resistance levels, but that a high friction and drainage potential (the latter produced by aggregate with a minimum gradation of 1/4 inch) is needed to also assure good slip and skid resistance at high vehicle speeds."

Skid Number-Speed Gradient

Adequate macrotexture, which reduces the loss in skid resistance by enabling the pavement surface to prevent the buildup of high water pressure under the tire imprint, is a necessary property in the provision of good skid resistant qualities of a pavement surface for high speed conditions. High wet weather skidding accident rates have been shown to result from inadequate macrotexture.

The skid number-speed gradient has been correlated with the various macrotexture measuring procedures (sand patch, grease patch, outflow meter, etc.). It also is affected by internal drainage into the pavement surface which might not be identified by these procedures. Speed gradients measured under actual field test conditions of speed and water layer thickness are, therefore, more indicative of the true properties important to skid resistance than are the conventional macrotexture measuring procedures. Such speed gradient measurements are accomplished by conventional methods used to determine skid numbers.

The skid number-speed gradient (G) is a ratio of the change in skid number resulting from a change in speed to that change in speed. One method of describing the gradient is by the equation:

$$G_{A-B} = \frac{SN_A - SN_B}{B-A}$$, where A and B are the test speeds at which the skid number is determined.

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A low gradient as determined by this equation, is indicative of little change in skid number with change in speed. For high speed operation a low speed gradient as well as a high skid number is a desirable characteristic.

The amount of increase in speed gradient with traffic usage is an indication of the extent of mix consolidation for bituminous surfaces and of coarse texture wear for PCC pavement. Thus, knowledge of the behavior of the speed gradient and skid number under traffic exposure permits an evaluation of the rate and cause of deterioration of surface skid resistance properties of various combinations of aggregate, mix design and construction.

The tread on the standard tire used on most skid trailers provides some drainage channels for water between the tire and the pavement surface. A tire with less tread than the standard tire would suffer a larger loss in skid resistance at higher speeds than the standard tire on a wet surface with a high gradient. However, this same tire could retain the same skid resistance as the standard tire on a surface with a low gradient. As an example, data from a correlation study indicates that a relatively dense graded surface with a skid number of 40 measured at 40 mph, with a standard ASTM tire and a speed gradient from 40 to 50 mph of .4 would provide a skid number of only 27 to a smooth tire at 50 mph. An open graded surface with a gradient from 40 to 50 mph of .15 and the same skid number of 40 measured at 40 mph with a standard ASTM tire would provide a skid number of 38 to a smooth tire at 50 mph. This illustrates the large difference in friction available to a vehicle tire under actual operating conditions that could occur for two pavement surfaces with the same skid number as measured by the standard procedure but with different surface void properties as indicated by the speed gradient. The difference at higher speeds would be much larger than the eleven (38 minus 27) skid numbers at 50 mph. This is a matter of great importance in consideration of the large number of vehicles involved in skidding accidents which have low tread depth or which are traveling at higher speeds.

Skid numbers should desirably be measured at the posted speed limit or a maximum of 70 mph. When available equipment cannot be operated at the posted speed, measurements made at lower speeds may be used with the actual speed gradient determined for the particular pavement surface to estimate the skid number for higher speed.

Aggregate, Mixes and Construction Methods

Only gradations, mixes and construction methods specifically directed toward skid resistance properties should be used for pavement surfaces. Therefore, current pavement specifications, available materials, mix designs and construction methods should be examined to determine if the

-more-

resulting pavement surfaces provide and maintain proper skid resistance properties. This examination should include the determination of the frictional, polishing and durability characteristics of surface course aggregates, mixes and finishing procedures. Such tests as the insoluble residue test (ASTM method proposed) and the accelerated polishing test (British standard method) are available to determine polishing characteristics of aggregates in the laboratory. Test methods such as the outflow meter, sand patch test, stereo photo interpretation and measurements such as skid numbers and speed gradients are available to evaluate the skid resistance of completed pavements.

Sufficient data should be developed by laboratory testing correlated with field tests or by field tests alone to enable the designer to adequately predetermine the skid resistance properties, including the loss of skid resistance from traffic and the change in speed gradient throughout the design life of the surfacing. The determination of durability of the pavement skid resistance properties, the prediction of loss of the skid resistance due to polishing under traffic, and loss of surface voids and texture depth will require measurement data collected over a significant time period. However, reasonable estimates, sufficient for an evaluation of presently used surfaces can be obtained by measuring properties of recently constructed surfaces and of surfaces of similar design which have been exposed to large numbers of vehicle passes. The loss in skid number and the increase in speed gradient for the estimated volume of traffic obtained in this way can be assumed to be representative of the range in values to be expected for the combination of aggregate, mix design and construction tested.

NCHRP Report 37 establishes a rationale for development of a set of minimum recommended skid numbers (SN) for use in the determination of the need for correction of existing pavement surfaces and are not intended for use in design. The designer should attempt to attain the best skid resistance properties that can feasibly be provided and maintained throughout the life of the pavement rather than minimum acceptable values. Designs of surfaces which do not provide satisfactory skid numbers with corresponding low speed gradients at the completion of construction should be reviewed and necessary modifications made for future work.

Skidding potential is a function of traffic volume and the amount of time the pavement surface is wet as well as the speed of traffic and pavement skid resistance. The retention of high skid numbers and low speed gradients throughout the life of the pavement becomes essential for conditions of high traffic volume and high percent of wet pavement time.

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Estimate of Pavement Wear

Desirably, data on pavement wear should be obtained under traffic conditions for each combination of design mix, aggregate type and finishing procedure employed. Figure 1 shows examples of data for two mixes, plotted on log-log coordinates to produce a straight line relation. The slope of the line in log coordinates is the "wear factor," 'K.'" For the two scales shown, the slope may be measured directly. The steeper slope line shows a pavement mix which wears rapidly and is suitable only for low volume roads. The other curve shows a mix which wears slowly as is desirable on high volume freeways. The wear factor (K) is calculated by the following equation:

$$K = \frac{\text{Log } (SN_1) - (SN_2)}{\text{Log } (VP_1) - (VP_2)}$$

Where SN_1 = Initial skid number
SN_2 = Final skid number
VP_1 = Vehicle passes at SN_1
VP_2 = Vehicle passes at SN_2

The determination of the wear factor for a particular mix design with a particular aggregate and finishing procedure will enable an estimate to be made of the period until resurfacing will be needed for existing pavements of that particular design. For new construction, wear factors developed from mixes of the type to be constructed, with the particular aggregate under consideration will indicate the suitability of the pavement surface for the particular conditions.

In general, mixes should be designed so that losses in skid resistance during the design life do not exceed about fifteen skid numbers. For high volume traffic conditions, it is desirable to use mix designs and aggregates which will result in wear factors below .05. Conditions of high traffic volumes, high operating speeds and large percent of wet weather time will justify the provision of higher skid resistance and lower wear factors that result in better retention of high skid resistance. Low traffic volumes, and small percent of wet weather time may justify the allowance of a higher wear factor and a possible subsequent loss of skid resistance. However, polishing has been found to be less severe for a given number of passes spread over a number of years than it is for the same number of passes occurring in one year. Therefore, an aggregate which would polish rapidly under heavy traffic volumes may provide a relatively high level of skid resistance throughout the life of the surface on a low traffic volume road.

The wear factor as used here is an indicator of the loss of skid resistance of the total mix with traffic exposure and will be affected by the properties of the total mix rather than the aggregate alone. Wear factor is also dependent on the speed at which the skid number is measured. A stable mix or a durable surface which does not consolidate or wear under traffic will exhibit a much better wear factor at high speeds because of its ability to retain its initial speed gradient and its resistance to flushing.

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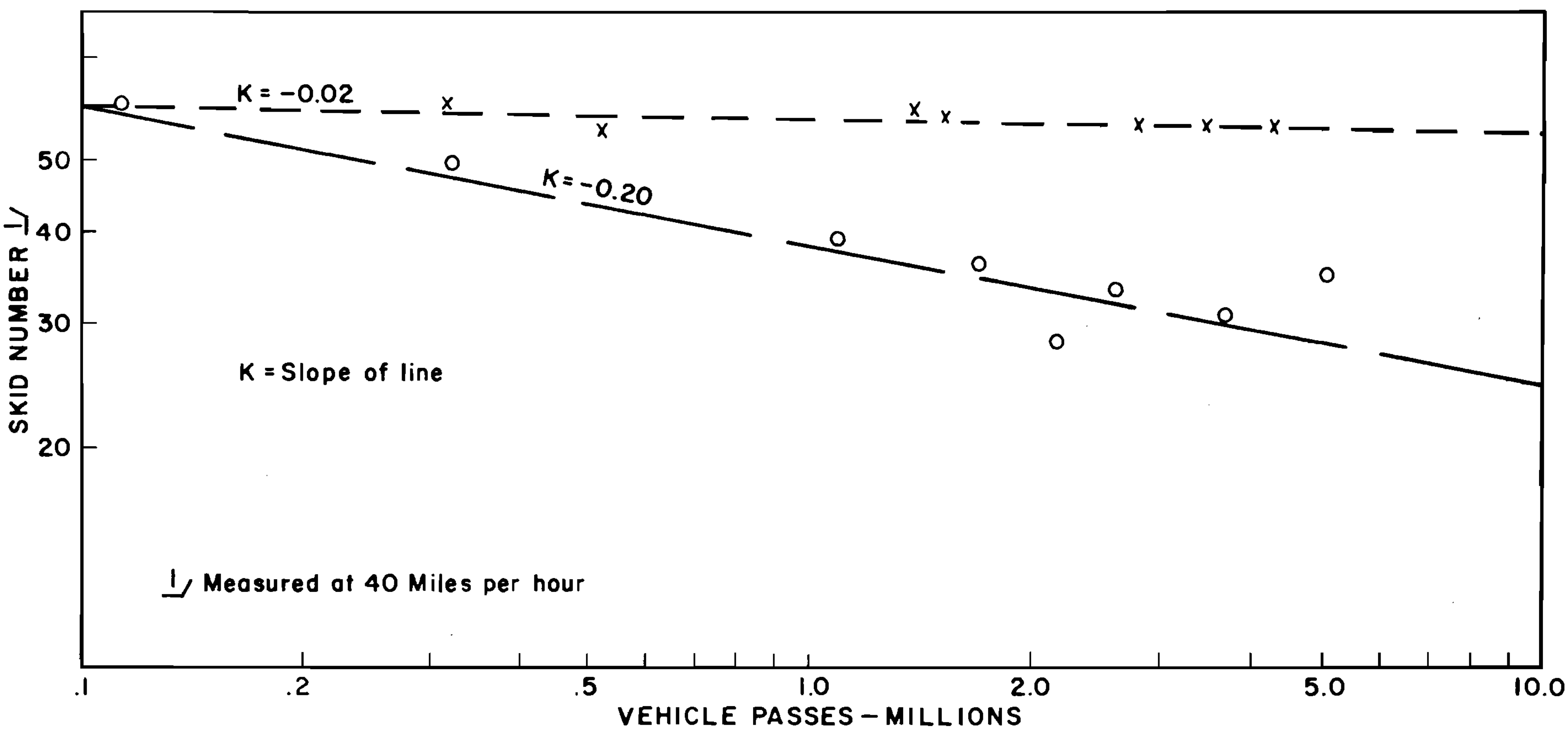

FIGURE 1 - PAVEMENT WEAR (POLISH) CURVES

The use of studded tires causes a very rapid loss of surface texture and results in a high wear factor. Frequent surface corrective work may be necessary to retain adequate texture where large volumes of studded tire traffic occur.

Design of Bituminous Surfaces

For high speed operations, bituminous surfaces with a relatively high percentage of larger size aggregate (+ 1/4 inch sieve) are required to provide the necessary surface voids. Voids are created by the provision of a high percentage of one-sized coarse aggregate. A reduction in the percentage of the one-sized aggregate either by an increase in the percentage of material smaller than the one-sized aggregate or by an increase in the percentage of material larger than the one-sized aggregate will result in a reduction in surface voids. On surfaces which have the necessary voids for high speed operations the tire of a vehicle will be primarily in contact with the coarse aggregate. The frictional properties of the coarse aggregate will, therefore, determine the skid resistance properties of a properly designed surface for high speed traffic. When small size material is incorporated in the mix, the relative area of coarse aggregate at the pavement surface which is in contact with the tire is reduced, which will result in a loss of effectiveness of the skid resistance properties of the coarse aggregate. Mixes capable of resisting consolidation under traffic are necessary to prevent loss in skid resistance. Consolidation further reduces the surface area of the coarse aggregate exposed, and increases the loss of coarse texture. Mixes with adequate surface voids and high resistance to consolidation, or with sufficient initial voids to tolerate consolidation without detrimental effects on skid resistance and texture, normally require either a high proportion of one-sized coarse aggregate or an asphalt content that is so low that the mix may have poor durability. A surface course composed of as large an amount of high quality one-sized coarse aggregate as is feasible, therefore, is desirable for high speed, high traffic volume conditions.

Very good surface void and skid resistance properties can be achieved with a plant mixed surface course, using a large percentage (about 60 percent) of one-sized coarse aggregate (3/8 to No. 4 sieve) limiting the amount of material on the smaller sieve sizes (maximum about 15 percent minus No. 8 sieve) and a high asphalt content (6-7 percent). These surfaces, known as open graded plant mix surface courses, also have superior riding qualities and greatly reduce spray from truck and automobile tires that obstruct the vision of passing vehicles.

The use of a substantial percentage of large size aggregate (3/4 inch or larger) or a surface treatment (chip seal) may produce the desired surface voids but may result in objectionable riding and noise qualities.

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The properties required for good skid resistance at the surface may be distinct from, and in the case of high voids, may be directly opposed to those desired in the structural mat. Specific designs and specifications for surface courses independent of the structural requirements of the mat are, therefore, required. The use of relatively small quantities of high quality material specifically chosen for surface conditions is feasible and should be practiced.

The use of special aggregates, even though considerably more expensive than locally available natural materials, may be necessary to produce the needed skid resistance qualities. The use of relatively small amounts of high quality material in a thin surface course may be cost effective particularly at critical highway locations and the use of these surfaces as part of initial construction is encouraged.

Design of Portland Cement Concrete Surfaces

Transverse texturing provides the necessary frictional quality for the frequent severe decelerations required by low speed traffic (operating speed less than 40 mph).

Longitudinal grooving, while not necessarily producing a large increase in skid resistance as conventionally measured, has been very effective in reducing high speed accidents with very dramatic reductions obtained on curves with high initial wet weather accident rates. Longitudinal grooving has also been effective in accident reduction on tangent sections. This suggests that longitudinal texturing may provide high friction perpendicular to the direction of travel (which would not be indicated by conventional skid testing procedures) enabling retention of vehicle directional control. Transverse texturing will produce higher skid numbers than longitudinal texturing as measured by the skid trailer for a given amount of texture. This may not, however, necessarily indicate a better or equivalent friction condition as related to accidents. The ability of either longitudinal or transverse texturing to prevent water pressure buildup between the tire and the wet pavement surface as indicated by the speed gradient will depend on the texture depth and the width and number of impressions. The "large" drainage channels provided by either longitudinal or transverse grooving are very effective in this respect. This drainage ability at least partially explains the effectiveness of grooving in accident reduction. Transverse texturing aids in surface runoff resulting in less wet pavement time. Combinations of longitudinal and transverse texturing of sufficient depth and width to provide adequate drainage both from between the tire and pavement surface and from the pavement surface itself provide the most desirable surface for high speed conditions. Approaches to at-grade intersections on high speed facilities, or other

-more-

special conditions requiring severe braking from high speed may require heavy transverse texturing, combinations of longitudinal and transverse texturing or other special treatment.

The inclusion of a good skid resistant aggregate (hard, sharp particles) and a low water cement ratio at the surface are essential for good skid resistance and durability. Overworking of the surface and the addition of water in the finishing operation will reduce durability and should not be allowed. When evaluating the adequacy of the surface for the design period the predicted loss in skid resistance and texture depth, based on anticipated traffic and the surface durability, should be considered.

In a portland cement concrete pavement surface, the necessary surface voids must be initially produced by proper texturing. A positive texturing method, capable of consistently producing textures of known quality should be specified. Wire brooming is more consistent in producing positive texture than is the burlap drag. However, the sharp projections produced are subject to rapid wear under traffic especially if the surface durability is poor. Grooves produced in the plastic concrete by fluted floats and combs have been reported to be more resistant to wear than the finer textures produced by the burlap or broom.

The skid resistance properties of the surface will depend on the coarse aggregate in the mix when the surface texture has worn away. The skid resistance qualities of the coarse aggregate are, therefore, important unless the surface is corrected by grooving or overlaying before the loss of surface mortar occurs.

APPENDIX B

COMMENTS ON THE SKID RESISTANCE INVENTORY

Skid Resistance Inventory

Speed Gradient:

The information shown in Table II was developed from data in Research Report 138-2 "Macro - Texture, Friction, Cross Slope and Wheel Track Depression Measurements on 41 Typical Texas Highway Pavements" and from unreported data collected on highly polished P.C. concrete pavements. There are two basic facts known about the speed gradient or loss in SN with increase in speed. First, the higher the friction of a surface (say high skid numbers at 20 mph) the greater the reduction in skid number values as speed increases. Second, small speed gradients are generally found where surfaces with large texture occur (or on those with good internal drainage as in Plant Mix Seals). In close study exceptions to the two basic facts occur to the extent that there is no exacting method of predicting the speed gradient. It is possible to measure the skid number at various speeds but in the survey testing proposed, the test cost increases proportionally with each pass of the test vehicle. Also, research in Texas indicates the speed gradient of the standard tests does not predict the speed gradients found in heavy (simulated) rainfall. Figure I shows the relationship found. In each case the speed gradients for both standard test and heavy rainfall was collected using the same trailer but in two of the points a new skid test unit was used to collect data. The data was obtained on Research Project 2-6-70-141.

Since the object of obtaining speed gradient information is to rank pavements as to the friction level available to the driver at high speeds in driving conditions during rainfall or wet weather and it is impossible to predict the friction in these conditions, the recommendations have been made to measure skid resistance at only 40 mph.

It is dangerous to use Skid Numbers to predict the actual friction available to any given vehicle. In a very general nature it is known that certain highways with low SN_{40} values are accident prone in wet conditions. Also, when the SN_{40} is improved the accidents are reduced, but when the SN_{40} value again begins to lower the accidents begin to increase. On certain other highways, when similar surface improvements are made the accident history is not improved. Even though accident reduction with improved SN_{40} values is much more prevalent, closer study is a natural reaction. This study reveals different vehicles and especially different manuevers require vastly different friction levels. Also, many factors affect the friction available to a vehicle on a given surface. The brochure "About The Skid Trailer" available in each District offers a complete understanding of the complexity of the problem than is available in the present space. It will never be possible to predict the friction available to a vehicle in any given accident event because it will be impossible to exactly duplicate the manuever performed, weather conditions which existed, etc.

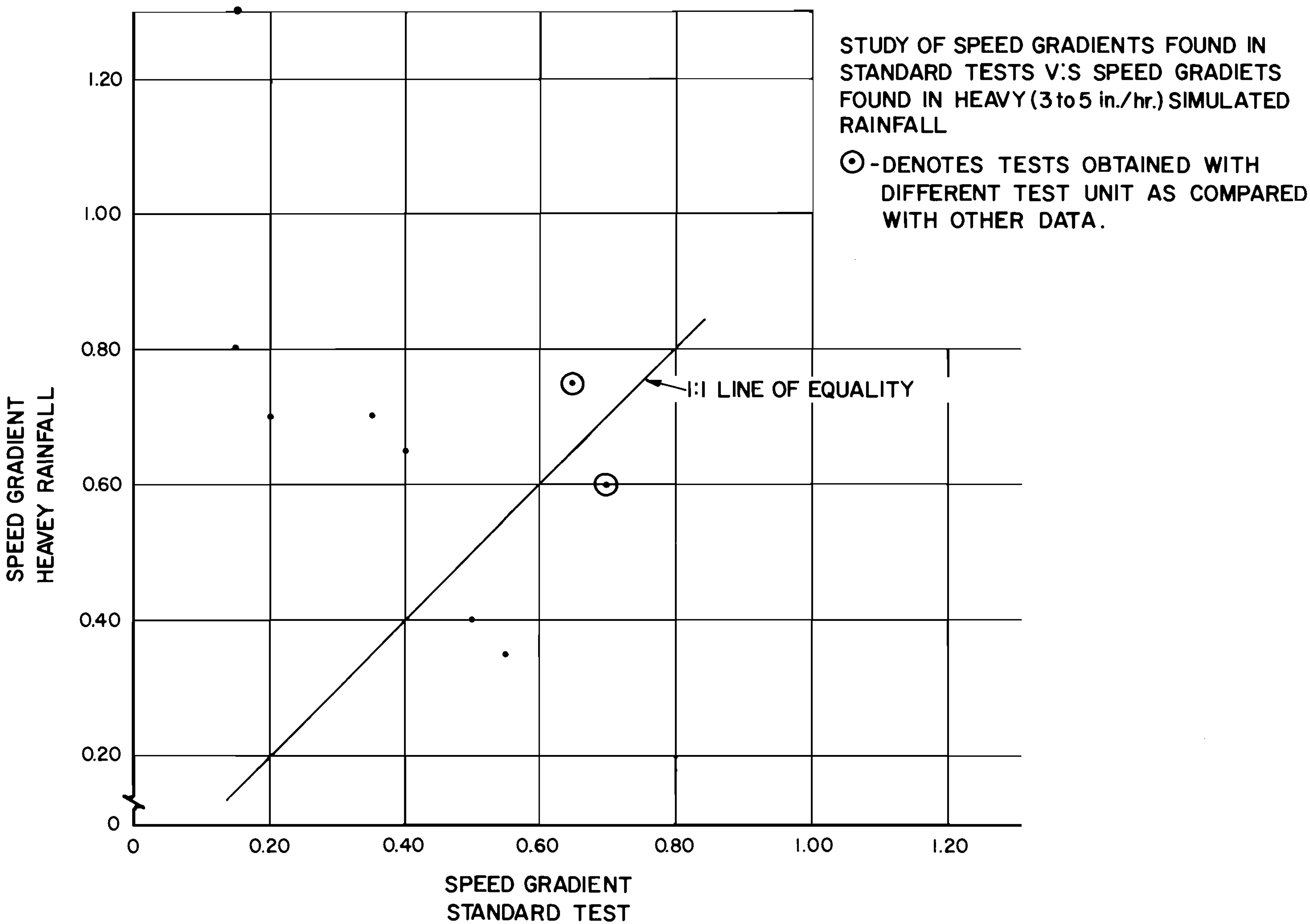
STUDY OF SPEED GRADIENTS FOUND IN STANDARD TESTS V:S SPEED GRADIETS FOUND IN HEAVY (3 to 5 in./hr.) SIMULATED RAINFALL
-DENOTES TESTS OBTAINED WITH DIFFERENT TEST UNIT AS COMPARED WITH OTHER DATA.
1:1 LINE OF EQUALITY
SPEED GRADIENT
HEAVEY RAINFALL
1.20
1.00
0.80
0.60
0.40
0.20
0
0
0.20
0.40
0.60
0.80
1.00
1.20
SPEED GRADIENT
STANDARD TEST

FIGURE 7

APPENDIX C

Comments on

A Systematic Procedure For the Identification

and Correction of Hazardous Skid Prone Locations

A Systematic Procedure For the Identification and Correction

of Hazardous Skid Prone

Locations

Identification

The criteria found in the Identification portion of the above Item was based on studies of excessive wet weather accident rates, but the criteria are intended only as a guide. Information concerning the locations mentioned above will be forwarded to the Districts involved annually about September and it may be noted that several of the locations selected may be based on information in which over one year has elapsed since the accident event(s). Experience has shown that many of the sections or hazardous locations have been improved by the time the above information can be forwarded to the District Office concerned. The recommendations included herein are not designed to negate field improvements which can be accomplished before annual accident information can be forwarded but as an additional aid to determine those locations which have been overlooked.

Experience has also shown that the selection of hazardous locations by a method which utilizes numbers of accidents often contain accidents which might be termed "unusual accidents". These accidents are heavily dependent on driver error or an unusual event such as an animal in the travel way. At certain times these unusual events cluster at one location giving a false indication of a hazardous location for wet weather driving. For this reason a report showing a summary of each accident for the location selected (for the year in question) will also be forwarded to the Districts.

Control loss or a skidding type accident on wet roads are believed to be closely associated with wet weather single vehicle accidents and occasionally with multivehicle accidents where one vehicle has lost control and caused other vehicles to become involved. On rural highways, high speeds are involved on most occasions. Horizontal curves or maneuvers requiring cornering or turning appear to be particularly susceptable to skidding accidents. On highly developed urban roadways with numerous intersections it is difficult to assess the pavement surface because of the high probability of driver error, however, a braked vehicle requires much more surface friction than a vehicle rolling in a straight path. Also, rapid polish or quick loss of available friction may be expected in the area near intersections.

Most vehicle skids on wet pavement show skid marks which are white or lighter in color than the surrounding pavement. The lighter marks are very noticeable on pavement shoulders and at many sites the entire path of the skidding vehicle may be traced. It is believed that the water or steam escaping between the tire and pavement scours or cleans the surface, leaving the skid mark. The skid marks on shoulders are visible for a week and many times much longer. Clusters of these skid marks on a given roadway area are an indication of a hazardous location and even though the accidents which occurred prior may not have been reported, more serious accidents are eminent.

Correction

Little information has been developed which shows the benefit of corrective action. However, accident records of two Texas Districts over a period of eighteen months before and after surface revision are shown in Table III-C. The 362.85 miles studied are essentially all highway sections resurfaced in two Districts in the years 1970 and 1971. It is believed that several of the highway sections were resurfaced for structural reasons rather than as a cure for slick pavement problems. Note the ninth item. - Range of SN_{40} Value Increases Found On Sections Studied shows negative values on some highway types. This indicates the friction was higher before resurfacing than after resurfacing. When this event occurred, the before resurfacing value was usually extremely high which possibly indicates resurfacing for structural reasons.

The benefit or overall improvement in wet accidents is good with a 40 percent improvement in all wet weather accidents and a 49 percent improvement in wet weather single vehicle accidents when the average SN_{40} value was increased about 16. And item which should not be overlooked is the tenth (and eleventh) item. Of the Farm to Market highway Sections studied, 22 or 61.96 of 127.18 miles had no wet weather accidents either before or after resurfacing. This points to at least two facts: (1) Because a highway has a low SN_{40} does not necessarily indicate a high accident situation and (2) funding for resurfacing due to accident prevention is probably better used on the higher class (or the heavily traveled) highways. Or, where wet weather accidents (especially single vehicle accidents) are occurring on a given area of highway, a improvement in surface friction indicates significant accident reduction. Stated differently, for a given amount of funding available for improvement, the greatest improvement in accident reduction will be at the locations where the greatest numbers of accidents are occurring.

The friction developed between the tire and pavement is the factor which allows a vehicle to perform any given manuever. Therefore, a surface that has a low SN_{40} value is potentially hazardous in wet weather. The traveling public should be so informed.

TABLE III-C

BEFORE AND AFTER WET PAVEMENT

ACCIDENT INFORMATION

CORRESPONDING TO SURFACE MAINTENANCE

IMPROVEMENTS

ITEM	All Highways	IH	US	SH & Loops	FM
Total Length Studies (mi)	362.85	42.11	74.18	119.38	127.18
Total Wet Accidents Before Surface Maintenance	194	74	36	67	17
Total Wet Accidents After Surface Maintenance	116	38	31	38	9
Total Wet Accidents, Percent Decrease - Or Improvement	40	49	14	43	47
Wet Single Vehicle Accidents Before Surface Maintenance	105	44	19	33	9
Wet Single Vehicle Accidents After Surface Maintenance	49	20	9	15	5
Wet Single Vehicle Accidents Percent Decrease-Or Improvement	53	50	53	55	44
Average SN_{40} Increase	16	23	10	15	16
Range of SN_{40} Increases Found On Sections Studied	-9 to 31	15 to 31	3 to 20	-3 to 25	-9 to 27
Number Of Sections On Which No Wet Accidents Occurred Either Before Or After Maintenance	31	0	1	8	22
Length Of Sections On Which No Wet Accidents Occurred Either Before Or After Maintenance	90.45	0	3.33	25.16	61.96

APPENDIX D

Comments on

An Evaluation of Current Pavement Design,

Construction and Maintenance Practices

To Provide Adequate Skid Resistance

Properties For the Needs Of Traffic

An Evaluation of Current Pavement Design,

Construction and Maintenance Practices To Provide

Adequate Skid Resistance Properties For the Needs

of Traffic

The recommendations shown in the above item of the manual are believed to be sound and based on a large amount of experience. The Polish Value has been used sporadically throughout the state and has had serious setbacks because, initially, Polish Values were recommended which were too low. The transition between research to implementation resulted in the purchase of a new portable friction tester and the correlation between new and old friction testers revealed a equation which again changed the Polish Value recommended. Data based on the research values had been forwarded to the Districts in an attempt to make contractors knowledgeable of the test and materials so that aggregate costs would not be adversely affected. The changes in values caused the user to be wary. However, the British Wheel Test Consistently produces values which can be correlated the SN_{40} values found with the skid trailer on older, highly trafficked, flexible pavement surfaces where the same aggregate was used.

Likewise considerable experience has been accumulated by agencies using the Insoluble Residue test. Many states use the test in connection with the skid resistance characteristics of the coarse aggregate in flexible pavements.

Also, the "Sand Patch" texture test has been used for some time and especially on bridge decks. Research on wet weather accidents shows texture to be even more important than the Skid Number. It is postulated that this is because the accidents studied were in rural locations, mainly at high speed and the Skid Number was obtained in a standard test at a lower speed.

The recommended guidelines are not the ultimate. Basically, the recommendations indicate all surfaces on all highways polish similarly. In reality, many surfaces do not receive sufficient traffic to polish to their lowest extremity when considering the structural life of the surface. For this reason, the rate of polish or the loss in Skid Number with increased traffic applications is needed. The rate of polish may be used in conjunction with the estimated traffic applications to be incurred in the structrual life to determine the expected SN_{40} value at that time. The expected SN_{40} value may be analysed to determine if the skid resistance is still sufficient. Table IV-D shows information of the rate of polish on several pavement and material types. The data shown in the table was obtained by determining the average SN_{40} value from the surface of several hundred construction jobs. The table shows the general gradation for the pavement types, several aggregate types, the number of sections or construction jobs studied for each pavement-aggregate type, the logarithum value for the average SN_{40} value at 1000 traffic applications with number in parenthesis being the SN_{40} value, the logarithm of the average SN_{40} value at ten million traffic applications, and the K value or rate of polish.

TABLE IV-D

RATE OF POLISH OF SEVERAL PAVEMENT AND MATERIAL TYPES

Grade or Pavement Type	Aggregate Type	Number Sections Studied	Log SN_{40} @ 1000 Applications	Log SN_{40} @ 10 Million Applications	K (Slope of Log Plot)
	Seals and Surface Treatments				
1	Iron Slag	26	1.85 (71)	1.55 (35)	0.075
2	Iron Slag	93	1.85 (71)	1.60 (40)	0.063
3	Iron Slag	199	1.85 (71)	1.60 (40)	0.063
1	Silicious	37	1.65 (45)	1.37 (23)	0.070
2	Silicious	184	1.65 (45)	1.43 (27)	0.055
3	Silicious	225	1.64 (44)	1.45 (28)	0.048
4	Silicious	11	1.64 (44)	1.45 (28)	0.048
1	Limestone	35	1.80 (63)	1.37 (24)	0.108
2	Limestone	30	1.80 (63)	1.39 (25)	0.103
3	Limestone	39	1.81 (65)	1.42 (26)	0.098
3	Lightweight	9	1.85 (71)	1.62 (42)	0.058
	Asphaltic Concrete				
C	Iron Slag	60	1.81 (65)	1.62 (42)	0.048
D	Iron Slag	8	1.66 (46)	1.58 (38)	0.020
C	Silicious	53	1.60 (40)	1.50 (32)	0.025
D	Silicious	18	1.62 (42)	1.50 (32)	0.030
C	Limestone	36	1.65 (45)	1.50 (32)	0.038
D	Limestone	15	1.65 (45)	1.45 (28)	0.050
F	Limestone	3	1.60 (40)	1.52 (33)	0.020
Cold Mix Limestone Rock Asphalt		6	1.77 (59)	1.62 (42)	0.038
	Portland Cement Concrete				
CRCP	Iron Slag	11	1.67 (47)	1.59 (39)	0.020
CRCP	Silicious	42	1.69 (49)	1.60 (40)	0.023
Jointed	Silicious	18	1.68 (48)	1.58 (38)	0.025

Equation Format

$$\text{Log } SN_{40} = \text{Log } SN_{40} \text{ @ 1000 Traffic Applications } -K \text{ (Log Traffic Applications } - 3)$$

(DATA IN THIS TABLE IS NOT RECOMMENDED FOR USE)

The equation at the bottom of the table indicates one method of determining the expected SN_{40} value after any number of traffic applications greater than 1000. To use the equation three items are needed, (1) the initial as constructed SN_{40} value or the SN_{40} value at 1000 traffic applications; (2) the rate of polish of a given pavement - aggregate type shown as K in the table; and (3) the estimated number of traffic applications at the time of surface maintenance or revision. Each needed item may be obtained from the table for the pavement-aggregate type in question, with the exception of the estimated traffic in item 3, which should be based on the total traffic over the surface rather than the per lane traffic.

Figure 8 shows a typical plot from which the information in the table was derived. A plot of the SN_{40} value v:s traffic applications for any given surface generally shows a rapid polish or loss in SN_{40} values, initially and then a gradually decreasing SN_{40} value loss, revealing a curved plot rather than a linear plot. Therefore, a linear plot may be obtained by using log-log paper or using logarithmic numbers on an arithmetic paper such as the example shown in Figure 8. The data for Figure 8 was obtained from determining the average SN_{40} value from the surface of approximately 184 different construction jobs which used a Grade 2 silicious aggregate in a surface treatment or seal. When considering the SN_{40} values, note the antilog of 1.0 is 10 and the antilog of 2.0 is 100. In other words a large amount of data scatter is evident. For this reason the information shown in Table IV-D is not recommended for use. The data and equation format in the table does show a method which may be utilized in the future.

Experience and theory indicates the scatter shown in Figure 8 is due to at least two factors, (1) the variation in materials found in a general aggregate type and (2) the variation in surfaces found between (and within) construction jobs.

The British Wheel test has shown each source contains aggregate with unique polish characteristics which can be greatly different between sources. There is also variation within the source pit. Therefore, considerable variation in the polish characteristics could be found when considering a general aggregate type due to the source encountered.

The second factor, construction variation, is obvious for a surface treatment or seal because it is easy to visualize aggregate stripping or surface flushing. However, even new asphaltic concretes with the same material, placed by the same laydown machine have been measured which exhibit skid resistance values varying as much as 30 skid numbers. It is postulated that this extreme variation can be explained with texture measurements, even though this postulation is reinforced only by visual observation and has not been proven with tests.

Therefore, it is possible to obtain better and usable data by studying the skid resistance performance of an individual surface. The performance history is developed by making periodic skid tests on the individual surface in question. The skid resistance inventory which is required will facilitate this process if sufficient records are maintained on each surface tested. This record system has been established which will

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SURFACE TREATMENT
GRADE 2
SILICIOUS

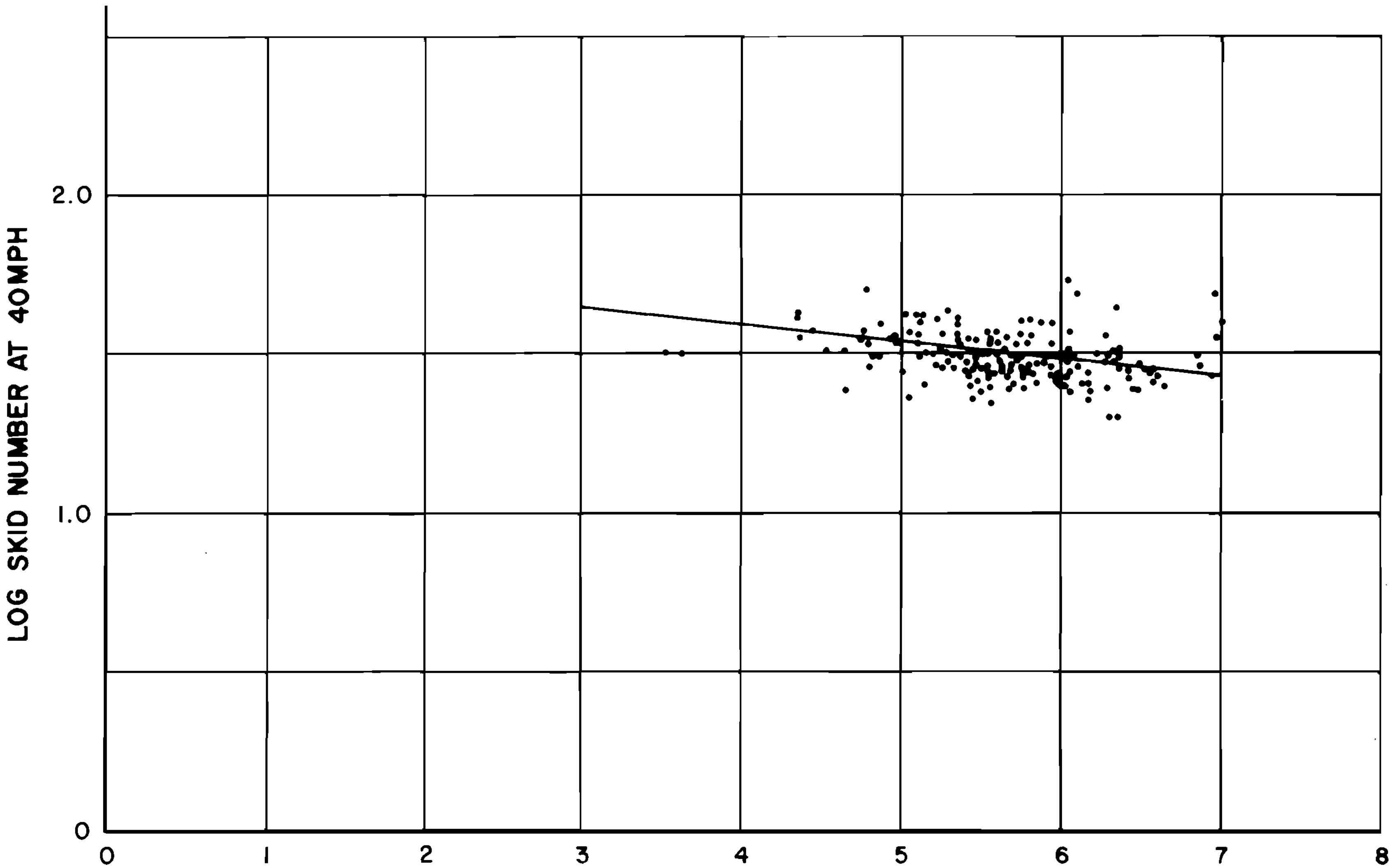

FIGURE 8

be explained in other publications. However, it will be possible after a few years of inventory to submit documental performance records of any pavement-aggregate type - source which has been placed in the District. Polish rates and expected variation in polish rate can be established by using methods similar to that shown in Table IV-D. It is also postulated that the rate of polish found with the SN_{40} periodic measurements on any given source can be correlated with the rate of polish found with the British Wheel Test. The initial friction value of a specimen(s) and the final polish value found with the British Wheel Test establish a polish rate when used in an equation similar to that in Table IV-D. It is believed that a correlation of the two polish rates will allow the District and contractor to select even a new aggregate and pavement which will provide a skid resistant surface at minimum cost.

Research is also studying a mehtod of predicting the skid resistance of an asphaltic concrete pavement by extending the present mix design procedure. Based on a stereo-photographic method of determining skid resistance from texture developed in Canada, the procedure uses the polish value to estimate coarse aggregate texture; insoluble residue to estimate intermediate aggregate texture and fine aggregate durability; aggregate gradation to estimate the large scale texture; and asphaltic content to estimate the large scale texture durability.