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INTERIM REPORT - PHASE 1
REVIEW, SELECTION AND CALIBRATION OF ACCELERATED WEAR AND SKID RESISTANCE TESTING EQUIPMENT

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Project IHR-406
Illinois Cooperative Highway Research Program

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Interim Report - Phase I
Review, Selection and Calibration of Accelerated Wear and Skid Resistance Testing Equipment

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Study co-sponsored by the U.S. Department of Transportation, Federal Highway Administration

The primary objective of this report is to convey the basis for selection of testing equipment being utilized during the conduct of Project IHR-406. Various techniques and devices were reviewed and selections were made prior to acquisition of specific items of equipment.

A further objective is to relate the progress that has been made on the research project since its inception on December 15, 1970. The major emphasis has been directed towards 1) calibration of the testing equipment, and 2) sample acquisition. Since only limited field work and laboratory testing to establish physical properties of select aggregates (Los Angeles abrasion, soundness, acid insolubles, etc.) has been performed to date, discussion of this effort is minimized in the report. A report for Phase 2 of the research project will contain a detailed discussion of the latter information and field test procedures used.

The report contains a summary of existing literature, project objectives and work plan, the established equipment requirements for measuring several parameters, and accomplishments to date. In addition, the procedures for use of the selected test equipment is outlined. The Appendices contain a brief description of alternate test equipment and procedures.

Successful conclusion of Project IHR-406 should lead to 1) a recommended method for preevaluating the wear and polishing resistance of aggregates, and 2) recommended aggregate acceptance levels to provide skid resistant pavement surfaces in Ill.
DISCLAIMER

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 Illinois Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.
REPORT OBJECTIVES

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TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2. FACTORS INFLUENCING SKID RESISTANCE</td>
<td>4</td>
</tr>
<tr>
<td>3. SUMMARY OF EXISTING KNOWLEDGE</td>
<td>9</td>
</tr>
<tr>
<td>4. PROJECT OBJECTIVES</td>
<td>19</td>
</tr>
<tr>
<td>5. WORK PLAN</td>
<td>21</td>
</tr>
<tr>
<td>6. ACCOMPLISHMENTS TO DATE</td>
<td>22</td>
</tr>
<tr>
<td>7. REQUIREMENTS FOR ACCELERATED WEAR AND POLISHING APPARATUS</td>
<td>24</td>
</tr>
<tr>
<td>8. BRITISH ACCELERATED WEAR AND POLISHING MACHINE AND TESTING PROCEDURE</td>
<td>26</td>
</tr>
<tr>
<td>General</td>
<td>26</td>
</tr>
<tr>
<td>Apparatus</td>
<td>26</td>
</tr>
<tr>
<td>Data Obtained from Test</td>
<td>30</td>
</tr>
<tr>
<td>9. REQUIREMENTS FOR SKID RESISTANCE TESTING EQUIPMENT</td>
<td>33</td>
</tr>
<tr>
<td>10. BRITISH PENDULUM TESTER AND TESTING PROCEDURE</td>
<td>36</td>
</tr>
<tr>
<td>General</td>
<td>36</td>
</tr>
<tr>
<td>Apparatus</td>
<td>36</td>
</tr>
<tr>
<td>Data From Test</td>
<td>41</td>
</tr>
<tr>
<td>11. REQUIREMENTS FOR SURFACE TEXTURE MEASURE</td>
<td>42</td>
</tr>
<tr>
<td>12. STEREOPHOTOGRAPHIC METHOD FOR EVALUATING PAVEMENT SURFACE Texture</td>
<td>48</td>
</tr>
<tr>
<td>General</td>
<td>48</td>
</tr>
<tr>
<td>Apparatus</td>
<td>48</td>
</tr>
<tr>
<td>Texture Code Number</td>
<td>50</td>
</tr>
<tr>
<td>Procedure</td>
<td>50</td>
</tr>
<tr>
<td>Application</td>
<td>51</td>
</tr>
<tr>
<td>13. CORRELATION OF BRITISH PENDULUM TESTER SKID NUMBERS WITH ILLINOIS SKID TRAILER VALUES</td>
<td>52</td>
</tr>
<tr>
<td>Section</td>
<td></td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>14. CALIBRATION OF BRITISH ACCELERATED WEAR AND POLISHING MACHINE</td>
<td></td>
</tr>
<tr>
<td>15. CORRELATION OF PHOTOINTERPRETED SKID NUMBERS WITH ILLINOIS SKID TRAILER</td>
<td></td>
</tr>
<tr>
<td>16. SUMMARY AND CONCLUSIONS</td>
<td></td>
</tr>
<tr>
<td>17. IMPLEMENTATION OF RESEARCH RESULTS</td>
<td></td>
</tr>
<tr>
<td>18. LIST OF REFERENCES</td>
<td></td>
</tr>
<tr>
<td>Appendix A</td>
<td></td>
</tr>
<tr>
<td>METHODS OF LABORATORY ACCELERATED WEAR AND POLISHING OF AGGREGATE AND MEASUREMENT OF SKID RESISTANCE</td>
<td></td>
</tr>
<tr>
<td>General</td>
<td></td>
</tr>
<tr>
<td>Purdue University Skid-Test Apparatus</td>
<td></td>
</tr>
<tr>
<td>University of Kentucky Investigation</td>
<td></td>
</tr>
<tr>
<td>University of Tennessee Equipment</td>
<td></td>
</tr>
<tr>
<td>National Crushed Stone Association Procedure</td>
<td></td>
</tr>
<tr>
<td>European Laboratory Test Methods</td>
<td></td>
</tr>
<tr>
<td>North Carolina State University Circular Track Wear Machine</td>
<td></td>
</tr>
<tr>
<td>North Carolina State University Jar Mill Wear Machine</td>
<td></td>
</tr>
<tr>
<td>British Accelerated Wear and Polishing Apparatus</td>
<td></td>
</tr>
<tr>
<td>Appendix B</td>
<td></td>
</tr>
<tr>
<td>METHODS FOR MEASURING PAVEMENT SURFACE TEXTURE</td>
<td></td>
</tr>
<tr>
<td>Appendix C</td>
<td></td>
</tr>
<tr>
<td>TEXTURE PARAMETERS OBSERVED IN STEREO PHOTOGRAPHS</td>
<td></td>
</tr>
<tr>
<td>Appendix D</td>
<td></td>
</tr>
<tr>
<td>LIST OF PERSONS INVOLVED WITH PROJECT IHR-406 AGGREGATE CHARACTERISTICS AFFECTING SKID RESISTANCE</td>
<td></td>
</tr>
<tr>
<td>Appendix E</td>
<td></td>
</tr>
<tr>
<td>WORK SCHEDULE AND PROGRESS CHART</td>
<td></td>
</tr>
</tbody>
</table>
1. INTRODUCTION

Skidding of motor vehicles on highways is an important contributing factor in many accidents. Of the approximately 55,000 deaths that are recorded in the United States alone each year through traffic accidents, it has been reported¹ that between 18 and 23 percent are the result of accidents involving skidding. Further, extensive studies of traffic accidents in the United States and elsewhere have shown that skidding is the direct cause of, or is an important factor in, 25 percent of the accidents on wet highways and 50 percent of the accidents on snow and ice covered highways.² Thus, the problem of skidding is of direct concern to highway users, to public officials responsible for the safety of the traveling public, and to those who manufacture and sell vehicles, tires, and paving materials.

The problem of skidding on highway surfaces has been recognized for many years. Use of gritty textured portland cement concrete and non-bleeding asphaltic surfaces for a time appeared to be a solution. However, additional experience showed that these surfaces do not always guarantee satisfactory skid resistance. Moreover, as traffic has increased generally, it is being found that clean surfaces that were once considered to be adequately skid resistant are being rendered deficient by the abrasive forces of increased traffic usage. Recent studies in Indiana have shown that for moderate traffic both bituminous and portland cement surfaces may lose as much as 50 percent of their initial skid resistance within two years.³

Slipperiness is often the only deficiency of otherwise structurally adequate pavements.
The establishment of the Interstate Highway System has made the need for highly skid resistant pavements even more important. Present and future concentrations of high speed traffic on the Interstate System will provide abrasive forces far in excess of those which are now known to be capable of reducing the skid resistance of the pavement by wearing and polishing.

A knowledge and understanding of 1) the frictional properties of pavements when wet or dry, b) the factors influencing the frictional properties, and c) the frictional requirements to start, stop, steer, and corner motor vehicles safely is required for developing built-in safety features in modern highway, street, intersection, and interchange pavements.

Pavements are worn and polished by traffic. The rate at which different pavements and the aggregates contained therein wear or polish varies, and the eventual "polish" at which the pavement stabilizes varies. Empirically, each highway department has a fairly good idea about which available aggregates polish more and which less. It is, however, important to learn which properties make a given aggregate a poor or a good risk for use in a surface course so that compliance with a standard can be predicted and cost comparisons between different available solutions can be made.

Before procedures of this type are feasible, a great deal more must be known about pavement wear and polishing than is currently known. Polishing is the consequence of wear, although the relationship between the two is not necessarily constant, even for a single material. It is influenced by many factors.

In attempts to date to investigate the wear and polishing characteristics of aggregates and paving mixtures, several different approaches
have been utilized (see Appendix A). Some of these approaches have yielded meaningful and useful information, while others have proved complex, time consuming, uneconomical, or unsatisfactory for providing the information desired. Efforts are continuing to establish a satisfactory method, based on one or more of the existing approaches, for use in Illinois.
2. FACTORS INFLUENCING SKID RESISTANCE

Research conducted in the United States and abroad has revealed that the following factors influence the skid resistance characteristics of a given pavement at a given time:

1. The characteristics of different types of aggregate, their hardness, angularity, grittiness and how they wear, polish, erode and dislodge from the pavement surface;

2. Surface texture, developed through the application of roughened textures with broom or burlap to concrete pavements, pavement grooving or other means such as gradation and binder quantity control;

3. Paving mixture proportions for both bituminous and concrete surfaces;

4. Surface additives to prevent slipperiness on existing surfaces;

5. Surface contamination, including the accumulation of oil, rubber particles, and mineral dusts, found on highway and runway surfaces;

6. Tire design and materials, type of construction, tread width, tread design, and inflation pressure;

7. Other factors, such as precipitation, surface drainage, braking method, wheel loads, hydroplaning, wheel size, vehicle speed, and temperature.

The most important single factor which determines the resistance to skidding under wet conditions of many types of pavement is the behavior of the aggregate that is exposed in the surface. Two important characteristics
of the aggregate in this respect are its resistance to polishing and its resistance to wearing. If an aggregate becomes smooth under the polishing action of pneumatic tired vehicles, the resulting road surface will have a poor resistance to skidding. If a polish resistant aggregate rapidly wears away under the action of traffic, then not only will the pavement soon lose its skid resistance because of the actual loss of the aggregate from the surface, but high speed skidding resistance will be lost even more rapidly because the planing away of the aggregate will remove the coarse texture of the surface which is necessary to give tires good traction at high speeds.

In Reference 3, the following statements relating to the subject are made:

"The antiskid properties of a well-designed pavement surface are dependent to a large degree upon the polishing characteristics of the mineral aggregate or aggregates of which the paving mixture is composed. Skid resistance will be dependent to a lesser degree upon the type of cementing agent, the gradation, and the openness of the mixture; but the ultimate state of pavement slipperiness will be dictated by the nature of wear of the pavement, which, in turn, is directly related to the resistance of the surface aggregate to polishing.

"This is true both for portland cement and bituminous paving mixtures. However, it usually requires less traffic to define the polishing characteristics of aggregates in bituminous mixtures, since the degree of exposure is greater for the individual pieces of aggregate than with portland cement surfaces.

"Although polishing of aggregates was noted occasionally in initial highway skid-resistance studies, only within the last decade (1950 to 1960) has pavement slipperiness due to polished aggregate become a problem of major importance to the highway engineer. Factors contributing to this recent development would include: (1) Both the number of vehicles and travel per vehicle have increased tremendously since World War II. (2) The flexing action of low-pressure passenger-car tires traveling at high speeds
exerts a 'squeegee' polishing effort on the pavement surface, in addition to the relative sliding between tire and pavement due to braking and acceleration. (3) High-pressure truck tires place an increasingly severe unit load on the components of the pavement surface. (4) Sand, frequently used in many localities for de-icing, tends to multiply the abrasive effects of the factors previously enumerated.

"If a reasonable degree of skid resistance is to be maintained on our highway system for anticipated high-volume traffic, it becomes increasingly important for the design engineer to give some thought to the polishing characteristics of mineral aggregates and to their effect upon pavement slipperiness."

As indicated previously, coarse texture in the surface, initially and after exposure to traffic, is desired. The macroscopic and microscopic texture of the surface is controlled initially by construction operations. After exposure to traffic for substantial periods, however, some of this texture is removed through wear and polishing. Subsequent surface skid resistance is obtained by aggregate particle macroscopic and microscopic texture. Thus, the aggregate used in a pavement surface has a most direct bearing on the level of skid resistance that exists on "older" pavement surfaces.

There is little difficulty in building a pavement surface to meet the texture requirements to give good skidding resistance. All modern forms of construction and materials can readily provide surfaces with a harsh texture when new and that can be given the necessary rough texture for high speeds if so required. The problem is that most highway surfaces tend to wear and polish under the action of traffic and some to close up to a smoother texture under heavy traffic.

The wearing and polishing of pavement surfaces has been recognized for many years and much work has been done, particularly with respect to the selection of aggregates which do not readily polish, to alleviate the
problem. The need for something more than a harsh surface on high speed roads has only come to the foreground in the last few years. However, there is now a trend towards the use of rougher looking surfaces on higher speed pavements.⁶

Angularity, steep slopes, sharp edges and points (all that go to make a surface harsh) increase the surface coefficient of friction. The scale of the asperities is relatively unimportant in itself, but small ones may be swamped in a thin film of water which large ones might penetrate. On the tops of large asperities, where pressures are likely to be high and water films, if present, very thin, small asperities should still be effective. Coarse, supposedly nonskid, surfaces can be quite slippery if the tops of the large asperities become polished and lose their harshness. Such surfaces, although slippery enough to be unsuitable for pavements, will not give the extremely low coefficients which fine textured surfaces can give. The only way to prevent or reduce polishing is to use a stone which is resistant to it.⁷

Measurements made in Illinois under an existing Illinois Highway Research Project, IHR-86, "Skid Resistance of Pavement Surfaces," have indicated that while pavements with portland cement concrete surfaces most often display acceptable tractive qualities, some fall below acceptable levels. Further, the skid resistance of bituminous concrete surfaces constructed with native aggregates varies considerably and ranges from well below to well above acceptable limits. It is believed that exhibited differences are, in part, a result of differences in the characteristics of the aggregates used for construction. The current research project (IHR-406) is directed towards investigation of this factor.
Although the other factors listed previously have been shown to influence skid resistance, they are not within the scope of the current investigation. Accordingly, discussion of these factors is not included herein.
3. SUMMARY OF EXISTING KNOWLEDGE

The following information relates existing knowledge pertaining to skid resistance and the role that aggregates have in influencing the polishing and skid resistance characteristics of pavement surfaces. The statements are based on 1) observations made by personnel of the Illinois Division of Highways with regard to pavement skid resistance, aggregate characteristics and/or problems associated with aggregates during pavement construction or design, or 2) excerpts from published material related to the subject area. These statements are not presented in any order of importance.

1. The specific type of pavement, concrete, or asphalt is not critical. Engineers can design and build antiskid surfaces into any type of pavement.\(^8\)

2. The Illinois Division of Highways (IDH) has placed antiskid surfaces with a number of "special" aggregates reported to possess better skid resistant properties than conventional aggregates available in Illinois. The aggregates generally have not produced surfaces with significantly higher skid resistances than those containing native aggregates and are generally too costly to be considered for use at other than "critical" locations. Among those with which IDH has had some experience are Synopal, wet bottom boiler slag, Iron Mountain trap rock, crushed siliceous gravel, and Gripstop (Kentucky rock asphalt). The IDH has also had some experience with rubber additives and a patented mixture containing an
additive called Tapisable. Special aggregates, additives and mixtures (which invariably add to the cost) must be carefully chosen, and even then may not produce outstandingly superior results.

3. Chip seal coats for routes with low traffic volumes and thin overlays for routes with high traffic volumes at present appear preferable as measures to improve skid resistance of existing pavements in Illinois.

4. One of the current problems in construction of treatments to improve skid resistance is that of retention of crushed limestone chips in bituminous material when applied as a crushed limestone seal coat.

5. A further and, perhaps, more pressing problem is that of developing specifications and tests for textural quality, for mineralogical composition, and for wear resistance of pavement aggregate.

6. Highway engineers have been studying the problem of vehicle skidding and the resistance to skidding offered by pavement surfaces for several decades.⁹

7. The best type of surface appears to be one of angular, non-polishing aggregate that produces a harsh surface texture, permeable enough to water so that excessive moisture or precipitation will drain away quickly.⁸

8. A number of diverse techniques and devices have been developed for measuring the skid resistance of pavement surfaces.⁹

9. The "Braking Force Trailer" method of measuring skid resistance
in the field is a simple and direct approach, is fast and accurate, and can be carried out at normal traffic speeds with minimum interference to traffic. This method has become the most popular one in the United States.

10. The factor which seems to have the greatest effect on slipperiness of pavements is the polishing characteristics of the mineral aggregate or aggregates of which the paving mixture is composed.\(^\text{10-12}\)

11. As much as 50 percent of the initial skid resistance is lost on some pavements during the first two years of service through traffic wear of the aggregates.\(^\text{9}\)

12. Quantitative characteristics of aggregates and of surface texture should be correlated with frictional resistance.\(^\text{9}\)

13. The coefficient of friction of a pavement surface is influenced significantly by the microtexture and the macrotexture of the surface.\(^\text{13}\)

14. A large scale macrotexture is required to provide high levels of skid resistance on wet surfaces carrying high speed traffic.\(^\text{14}\)

15. Accident studies support the need for a minimum pavement macrotexture (greater than 0.035 cu in./sq in. by sand patch method).\(^\text{15}\)

16. The skid resistance properties of an aggregate may be preevaluated in the laboratory before incorporating the aggregate in field pavements.\(^\text{16}\)

17. A definite need exists for additional information on polishing tendencies of aggregates under high traffic volumes and under varying traffic compositions.\(^\text{17}\)
18. The polishing tendency of a given aggregate is one of its distinct physical properties and, as such, must be dependent on some characteristic of that material, such as its petrology or mineral assemblage.  

19. Aggregates considered to be "polish resistant" include siliceous gravels, granites, greenstones, diabase, quartzite, sandstones and expanded shale. These materials can result in pavement surfaces that have a minimum coefficient of friction of 0.5.  

20. Limestone aggregates have resulted in pavement surfaces varying from excessively slippery to exceedingly nonskid. This results because carbonate aggregates can be a rather heterogeneous group of materials which possess varied physical, mineralogical and textural properties. 

21. Limestones which exhibit good antiskid characteristics are crystalline granular limestones composed of angular interlocking grains.  

22. Limestones which polish most readily possess either a very fine grained crystalline structure or consist of rounded oolitic grains in a calcite matrix of similar hardness.  

23. In Virginia, pavements produced with limestone aggregate exhibit an average coefficient of friction of 0.369. The range in friction values using this aggregate is 0.238 to 0.538.  

24. The acid insoluble test has shown considerable promise as a test for evaluating carbonate aggregates for desired skid resistant properties.
25. Use of aggregates with a relatively high acid insoluble content (greater than 10 percent) generally results in pavements with high skid resistance characteristics.\textsuperscript{9,12,19}

26. The amount of sand size insoluble residue, the residue gradation and the total amount of insoluble residue obtained from a coarse aggregate sample should be considered simultaneously in rating a carbonate aggregate as to its skid resistance. For a preliminary evaluation, the sand size portion seems to be a more reliable indicator than total residue as to the skid resistance performance of a carbonate aggregate.\textsuperscript{16}

27. Some states have prohibited the use of limestone fines in portland cement concrete.\textsuperscript{17}

28. Generally, carbonate aggregates will polish faster than other type aggregates because of the predominance of the soft carbonate minerals in their composition. The higher the percent and the harder the mineral proportion of impurities in a carbonate aggregate, the better will be its skid resistance performance.\textsuperscript{16}

29. Uniform fine grained or oolitic limestones consisting essentially of pure calcium carbonate should not be used in surface courses of pavements.\textsuperscript{11}

30. Some limestone quarries produce a more skid resistant type of aggregate than others.\textsuperscript{12}

31. Aggregate materials from the same quarry may exhibit a wide range in polishing and skid resistant characteristics.\textsuperscript{12}
32. In Virginia, granite, silica sand and gravel result in pavements with an average coefficient of friction of 0.474. The range in friction values using these materials is 0.43 to 0.72.¹⁰

33. Sandstones possess the best resistance to polishing.¹¹

34. Gravels are heterogeneous aggregates and because of this it is difficult to relate polishing resistance to any basic characteristic.¹¹

35. Pavements made from aggregates composed predominantly of the same mineral or of minerals having a narrow range of hardness, like most limestones, diabase, and some quartz gravels, will polish faster than aggregates composed of minerals with a wide range of hardness (H) as measured by Moh's scale, such as sandstone, granites, gneisses and slates. Obviously, the softer the mineral composition, the faster is the rate of polishing.¹⁶

36. There seems to be an optimum compositional proportion of hard to soft mineral grains in a mineral aggregate for high skid resistance performance. The optimum seems to fall in the range of 50 to 70 percent of the hard minerals \( (H \geq 6 - 7) \) to 30 to 50 percent of the soft minerals \( (H \leq 2 - 3) \). The influence of this compositional proportion is apparently modified by the size, shape, and distribution of the mineral grains in the aggregate particles. The larger and the more angular the hard mineral grains, and the more uniform their distribution in the
softer mineral matrix, the higher is the resulting skid resistance of the aggregate.\textsuperscript{16}

37. Pavement surfaces made from aggregates having approximately the same mineral composition but differing grain shape and/or size will produce differing skid resistance levels. The more angular and the larger the grains in individual aggregate particles, the higher is the skid resistance of the aggregate particles when incorporated in pavement surface.\textsuperscript{12,16}

38. Microscopic and petrographic examination of worn highway surfaces and of aggregates used in the surfaces can lead to establishment of criteria for selecting aggregates with good skid resistance characteristics.\textsuperscript{12}

39. Petrographic descriptions and photomicrographs of aggregates provide a fruitful source of information for relating aggregate properties and antiskid characteristics.\textsuperscript{11}

40. There appears to be no relationship between any of the standard physical tests (percent absorption, loss on abrasion, etc.) and the resistance to polishing of an aggregate in a bituminous mixture.\textsuperscript{11}

41. An aggregate that wears in a differential manner will maintain its skid resistance quality. A lack of consistency of structure or of grain size appears to be essential for good skidding resistance.\textsuperscript{8,11,16}

42. Several accelerate-wear techniques exist and others are under development.\textsuperscript{9}
43. There is continuing need for laboratory investigations and for reliable accelerated simulation of wear and performance under traffic.\textsuperscript{9}

44. Simulation of traffic wear and polishing on pavement surfaces and/or aggregate surfaces is a problem associated with laboratory investigations.\textsuperscript{9}

45. General conclusions from a complex investigation\textsuperscript{18,20} of the dependence of an aggregate's ability to resist polishing on its petrology reported in 1960 are:

a. In igneous rocks, those petrological features which affect polishing most readily are a variation in the hardness between the minerals, and the proportions of soft minerals present;

b. Rocks which have cracks and fractures in individual mineral grains are less susceptible to polishing because such grains are weak and pluck out of the matrix;

c. High skid resistance appears to be related to the presence of an insoluble residue (especially if residue is quartz), and to the presence of coarsely crystalline patches of carbonate.

46. Skid resistance in almost all cases (sandstone excepted) declines rapidly at first and then more gradually until an ultimate state of polish is virtually reached.\textsuperscript{16}

47. The specifications of several states do not permit the use of dolomite, limestone, or other aggregates tending to polish
under traffic in surface courses on pavements expected to carry relatively heavy traffic.  

48. Renewing an aggregate surface as the surface wears is considered of primary importance for providing pavements with adequate skid resistance.  

49. Pavement surfaces made from any type of crushed aggregate will initially have medium to high skid resistance, but most aggregates will eventually polish under sustained and prolonged traffic action.  

50. In general, bituminous pavement surfaces exhibit lower skid resistance values than portland cement concrete surfaces. If appreciable exposure of the coarse aggregate occurs in both surfaces, however, the two surfaces will be similar and give about the same skid resistance characteristics.  

51. Dense graded bituminous mixtures exhibit somewhat better skid characteristics than open graded mixtures composed of the same aggregate provided they do not have excess asphalt at the surface.  

52. The larger grades of aggregate apparently give more skid resistance in bituminous surfaces, finer aggregates are better for skid resistance in concrete.  

53. Bituminous surfaces that bleed are slippery. Concrete pavements finished with excess cement paste or mixed with too much sand or water are slippery.  

54. Surface contamination contributes to lower skid resistance and promotes the wear and polishing of aggregates at the pavement surface.
55. Even the most skid resistant surface is slippery, if covered by ice, snow, mud, wet leaves, etc.\textsuperscript{21}

56. Excessive asphalt in bituminous pavements may produce wet surface friction coefficients as low as 0.10 to 0.20.\textsuperscript{9}

57. Ice covered pavements may have coefficients of friction as low as 0.05.\textsuperscript{9}

58. The coefficient of friction of a snow packed surface may be as low as 0.15.\textsuperscript{9}

59. Some synthetic aggregates have yielded surfaces of high initial and relatively constant levels of skid resistance.\textsuperscript{22}

60. Slag may provide high initial skid resistance. However, one study\textsuperscript{23} of a Pennsylvania Turnpike section had an SN of 77 at two months, 33 at two years, and 26 at four years.

61. Calcined bauxite, when applied as a surface treatment and embedded in an epoxy type binder, has exhibited superior and lasting levels of skid resistance. However, this material costs approximately $80 per ton.\textsuperscript{24}
4. PROJECT OBJECTIVES

The primary objective of Project IHR-406 is to determine 1) the wear resistance and polishing characteristics, and 2) the petrographic features of aggregates used in pavement surfaces in Illinois and to relate this information to the field performance of pavement surfaces containing the aggregates.

In general, those parameters of aggregates directly related to their use that have an important bearing on skid resistance will be studied.

The project staff will:

1. Determine properties of aggregates which influence wear, polishing and skid resistance, and develop petrographic, geologic, chemical and physical bases for evaluation of the susceptibility of aggregates to wear and polish;

2. Determine the wear resistance and polishing characteristics of selected Illinois' aggregates used in pavement construction, relate these characteristics to the skid resistance of pavement surfaces incorporating these aggregates and indicate the long-term skid resistance potential of pavements or surfaces constructed using these selected aggregates;

3. Through laboratory testing and correlation of the results of laboratory and field testing, develop criteria for evaluating Illinois' aggregates for use in skid resistant pavements.

The objectives of the project as set forth were established to complement a field study of pavement skid resistance characteristics being
conducted by the Illinois Division of Highways as Study IHR-86. Further, the objectives follow the indicated "Needs for Research" on a national basis contained in the final report of the National Cooperative Highway Research Program Project 4-8, 1968. Similar needs exist in Illinois.
5. WORK PLAN

The work plan for Phase 1, Review, Selection and Calibration of Existing Accelerated Wear and Skid Resistance Testing Equipment, as set forth in the original Project Prospectus is as follows:

1.1 Determination of requirements for a device or devices to perform accelerated wear or polishing of single or multiple aggregate samples and pavement cores.

1.2 Determination of requirements for a rapid measure of surface texture and skid resistance.

1.3 Acquisition and calibration of an accelerated wear device.

1.4 Calibration of instrumentation to measure skid resistance and instrumentation to measure surface texture.

1.5 Preparation of an interim report describing method for accelerated wear of aggregate samples and pavement cores, instrumentation for surface texture measurement and instrumentation for skid resistance measurement.
6. ACCOMPLISHMENTS TO DATE

A thorough review of the literature was conducted and the requirements for a laboratory and field skid resistance measuring device, an accelerated aggregate wear and polishing apparatus, and a pavement surface texture measuring procedure were established. A British Accelerated Aggregate Wear and Polishing Apparatus and a Bronica Camera were obtained. Microscopic equipment at the University of Illinois was located and needed accessories were purchased. Existing University equipment to conduct sieving, crushing, weighing, mixing, cutting and soaking (controlled water baths) of specimens and a binocular enlarging stereoscope for reducing photographs was amassed.

Initial collection of data was accomplished to permit correlation of the British Pendulum Tester "skid" values with

1. State skid trailer skid resistance values;
2. Surface texture parameters obtained from the stereophotographs; and
3. The aggregate Polished Stone Value (PSV) determined after testing on the British Accelerated Wear and Polishing Apparatus.

A standard aggregate was imported from England (Road Research Laboratory) and is being used to establish a standard aggregate in Illinois and to permit correlation with previous work performed in the subject area by other agencies.

During the summer of 1971, extensive field work was performed by the University staff in cooperation with research personnel from the Ottawa
Physical Research Laboratory of the Illinois Division of Highways. Approximately 50 sites were selected (with basis on previous IDH work) and studied. Field measurements taken at each of four locations at each site included: state skid trailer skid resistance values, skid resistance values as measured with the British Pendulum Tester, stereophotographs of the pavement surface at the time of test, and one core from each location (four per site).

In addition, a staff geologist obtained aggregate and rock samples from the quarries that supplied materials to the sites under study. The aggregate and rock samples are being subjected to detailed laboratory analysis.

Thin sections from one core obtained from each site studied are being prepared and subjected to petrographic analysis. The information obtained is to be related to the wear potential of the various aggregates being studied.

Laboratory testing is being performed to establish physical and chemical properties of the aggregates utilized in the 50 sites studied to date. Los Angeles abrasion values, soundness values, hardness, and acid insoluble residue contents are being established. Correlations between each property and the exhibited skid resistance of surfaces incorporating the aggregate will be established.
7. REQUIREMENTS FOR ACCELERATED WEAR AND POLISHING APPARATUS

A review of the literature of current methods (see Appendix A) of wearing and polishing test samples of aggregates or pavement mixtures in the laboratory led to the formulation of the following "requirements" for an accelerated wear and polishing apparatus for use on Project IHR-406. The requirements are not listed as to order of importance.

1. The test procedure should produce a degree of wear and polishing comparable to that developed in a pavement surface under traffic.

2. The test equipment and procedure should not be new. An existing method was to be selected based on suitability and anticipated future use throughout the United States.

3. The test specimen size must not be too large.

4. The time required for conducting the test must be relatively short.

5. Test results must be reproducible for specimens of the same aggregate within a test run and between two different test runs.

6. A method that utilizes a pneumatic tire to develop wear and polish should be selected.

7. Results from prior tests should show good correlation with some measure of skid resistance as obtained in the field.

8. The method should permit definitive results to be obtained for aggregates of different quality so that effective pre-evaluation of aggregate performance can result.
9. The cost of initial test equipment and equipment operation should not be excessive.

10. The test procedure should be relatively simple to permit conduct by laboratory technicians.

11. The test results should not be significantly influenced by different test operators.

12. The testing device should have the capability of wearing and polishing specimens of aggregate prepared in the laboratory and specimens prepared from cores recovered from a pavement surface in the field.

13. The capability should exist for testing more than one specimen in a given test run.

14. The "mode" of wear and polish (specimen rotation relative to wear tire) should simulate that expected in field surfaces subjected to traffic.

15. The test surface should lend itself to more than one method for measuring the frictional properties of the surface before and after the accelerated test.

16. The test equipment and procedure should lend itself to standardization.

17. The test should be applicable to nonconventional as well as conventional aggregates.
8. BRITISH ACCELERATED WEAR AND POLISHING MACHINE AND TESTING PROCEDURE

General

In the late 1950's, the Road Research Laboratory (RRL), London, England, developed a laboratory test for investigating the extent to which aggregates used in pavement surfaces will wear and polish when subjected to heavy traffic conditions. Considerable effort has been expended by personnel of RRL in the past decade to comparing the results of the test with the extent to which aggregates become polished and with the slipperiness of the pavement surface in which the aggregate is contained. The results of the research provided satisfactory evidence that the laboratory test reproduces the polishing of aggregates that takes place on the field pavement. Accordingly, the test was adopted as a British Standard (BS 812:1967) for use in preevaluation of aggregate performance.

Apparatus

The British Accelerated Wear and Polishing Apparatus is depicted in Fig. 1. The apparatus was designed to obtain a rapid rate of wear and polish by passing each specimen of aggregate under a pneumatic tire driven at a speed of 300 to 320 rpm (15 mile/hr). Aggregate specimens are prepared and mounted on a 16-in. diameter wheel having a flat periphery 2-1/2 in. wide. The aggregate surface which is formed is in contact with an 8-in. diameter pneumatic tire with an inflation pressure of 45 psi. The pneumatic tire is pressed onto the specimen (pavement) surface with a normal load of 88 lbs, by means of lever arm and dead weight. The tire is free to rotate
Fig. 1 British Accelerated Wear and Polishing Machine at the University of Illinois
on its own axis and is driven by friction between the tire and the aggregate surface.

Coarse grit (50 to 100 $\mu$) to produce accelerated wear or fine grit (less than 300 $\mu$) to cause polishing is fed from a hopper through a chute onto the aggregate specimen surface prior to its passing under the tire. The hopper is equipped with a vibrator to promote a uniform rate of flow of either abrasive.

Water is fed to the chute from an aspirator. (Recent research indicates that an atomizer may result in more uniform water application.)

Aggregate specimens are prepared in the laboratory from about forty 3/8-in aggregate particles. The aggregate particles are cemented with an alumina cement paste and are distributed over an exposed surface in each specimen which measures 3-1/2 in. by 1-3/4 in. A typical specimen is shown in Fig. 2.

Due to the method of sample preparation, the great majority of the aggregate particles per specimen present a relatively flat surface to the pneumatic tire. During test, tire contact is made over the entire length of each specimen and over 1-1/8 in. of the width. Fourteen specimens are tested during each six hour run, normally consisting of four sets of specimens (three specimens of the same aggregate per set) and two specimens of a standard aggregate.

Details relating to specimen preparation, the rate of grit and water feed, and the actual test procedure can be obtained from the British Standard Test Procedure (BS 812:1967).26
Fig. 2  Mold and Specimen for Accelerated Wear and Polishing Test
Data Obtained from Test

The change in the surface characteristics of the aggregate specimens at intervals of time during the accelerated wear and polishing test is measured in terms of the frictional resistance to the passage of a wetted rubber slider across the wetted surface of the specimen under a fixed normal load. The British Pendulum Tester (BPT) described in Section 10, modified to use a slider with dimensions of 1-1/4 in. by 1-3/4 in. and equipped with a calibration scale (which accounts for the reduced slider contact length as a result of specimen curvature is employed for the measurement.

Examples of the results of accelerated wear and polishing tests performed by RRL on five different aggregates are shown in Fig. 3. The curves shown in the figure demonstrate the range of effects that can be obtained for different aggregates. The first graph (Type A stone) is representative of an aggregate that exhibits little or no polish during the standard test, while the last graph (Type G stone) represents an aggregate that exhibits a high degree of wear and polish.

To compare the extent to which different aggregates wear and polish when subjected to pneumatic tire traffic, the RRL has found it sufficient to quote the BPT coefficient obtained at the end of the six hour test run. The final coefficient has been termed the Polished Stone Value (PSV) for the tested aggregate.

For Project IHR-406, the PSV value for select aggregates in Illinois, as established by the British standard test procedure, is being determined. In addition, an index of the change in the frictional
Fig. 3 Typical Results Obtained from the British Accelerated Wear and Polishing Test on Aggregates (after Road Research Laboratory)
coefficient during the test is being calculated. It is believed that an aggregate possessing a high initial coefficient and a low final coefficient (PSV) should be a better material for some pavement applications (surface) than is an aggregate that exhibits little or no polish, but has a low coefficient throughout the test.
9. REQUIREMENTS FOR SKID RESISTANCE TESTING EQUIPMENT

Early attempts to measure the phenomena that take place in the zone of contact between a skidding tire and a wet pavement surface involved measurements made with vehicles in an actual skidding mode of operation or through the use of full scale testing machines, such as the skid trailer. Difficulties due to size of equipment and inherent difficulties of controlling the various factors that influence test results were experienced and suggested that more satisfactory ways of measuring the desired surface property be investigated. Accordingly, test devices and several procedures have been developed in recent years (see Appendix A).

The requirements for a mechanical device for measuring the skid resistance characteristics of surfaces for Project IHR-406 were formulated after a thorough review of literature pertaining to existing skid resistance measuring devices. These requirements are presented below and are not listed as to order of importance.

1. The device should provide a rapid measure of the skid resistance characteristics of a pavement surface.
2. The device and procedure must be applicable for use in the laboratory and in the field.
3. The results of the testing procedure must correlate with the results of full scale testing machines such as the State skid trailer.
4. The method of test should be relatively simple to allow conduct by technicians.
5. The device should be portable.
6. The cost of initial test equipment and equipment operation must not be excessive.
7. The testing device and procedure must result in a *minimum* of hazard to both traffic and operator during use.

8. The device must be capable of measuring friction values on grades, curves, and highly crowned surfaces in the field.

9. A large area of the test surface should not require wetting (flooding) for test purposes.

10. The size of the test surface should not be too large. (The device should be adaptable to laboratory prepared surfaces and surfaces of cores recovered from pavements in the field.)

11. The equipment and testing procedure should *not* be new. (Prior evaluations should suggest the possibility of obtaining desired correlations.)

12. The apparatus should be capable of yielding highly consistent readings for a specific test surface at a given location.

13. The instrument should maintain a high standard of accuracy without requiring elaborate maintenance and in spite of long periods of use in inclement weather.

14. The average pressure over the contact area should be of the same order as that between a tire and the pavement surface.

15. The instrument should give a direct reading of the property measured.

16. Environmental factors should not influence test results. (This requirement can be set aside if corrections can be applied to account for environmental influence.)
17. The contact surface should permit measurement of a friction coefficient as influenced by microtexture of an aggregate particle and the macrotexture of the surface incorporating the aggregate.

18. The test procedure should be adaptable to standardization and should be acceptable to several engineers and researchers as a method of test.
10. BRITISH PENDULUM TESTER AND TESTING PROCEDURE

General

A number of devices have been developed to measure the frictional properties of pavement specimens in the laboratory or, by being adaptable to both laboratory and field testing, to serve as a link between them. Among these instruments are the pendulum type, the single wheel type, and the skid cart testers. These and other laboratory techniques vary in their design and accuracy and have been described in detail in the literature of skid resistance.\textsuperscript{16,23,27-30}

A portable type instrument, the British Portable Skid Resistance Tester,\textsuperscript{16,27,29} known also as the British Pendulum Tester (BPT), is of particular interest because it was the instrument selected to measure skid resistance in the IHR-406 study.

Apparatus

The British Pendulum Tester is shown in Fig. 4. It is a dynamic pendulum impact type tester and is based on the principle of energy balance. On release from a horizontal position, a pendulum arm (see Fig. 5) of fixed radius (20 in.) and weight (5 lbs) falls freely under gravity and a rubber slider affixed to the end of the arm makes contact with a surface under a preset normal load and for a specific contact length. The angle between the pendulum arm and the horizontal after the slider passes over a surface is a measure of the energy absorbed by the surface. A large angle indicates a high energy loss, whereas a small angle indicates little or no energy loss.
Fig. 4 British Portable "Skid-Resistance" Tester
Fig. 5 Mechanism of Pendulum of British Portable Tester

(After Road Research Laboratory)
Two sizes of rubber slider are available for use with the apparatus and the one to be selected depends on the dimensions of the test surface. For standard use, a 1-1/4 in. by 3 in. rubber slider which sweeps over a flat test surface for a contact distance of 8 in. is employed. For use in conjunction with British Accelerated Wear and Polishing Test specimen and with small diameter (4 in.) field cores, a 1-1/4 in. by 1-3/4 in. rubber slider which makes contact with the specimen surface for a contact distance of 3 in. is employed. When the smaller slider is used, it is necessary to have an auxiliary scale on which scale dimensions are reduced in the ratio 3:5 (the ratio of contact distances). Apart from these modifications, the tester remains unchanged.

When the pendulum arm is released from a fixed initial horizontal position, it carries a pointer along a circular scale calibrated to read frictional measurements known as British Pendulum Numbers (BPN). The numbers range from 0 to 150 and represent a frictional coefficient $\times 100$.

The instrument calibration is derived from the fact that energy lost by the pendulum during the swing is equal to the work done in overcoming the friction between the slider and the surface. Thus,

$$\text{Work done against friction} = \mu PD$$  \hspace{1cm} (1)

where

$\mu = \text{coefficient of friction between slider and surface}$

$P = \text{average normal load between slider and surface}$

$D = \text{sliding distance}$

and
Loss in energy of the pendulum arm = $W(H-h)$ \hspace{1cm} (2)

where

$W$ = weight of the swinging arm

$H$ = initial height of the center of gravity in the release position

$h$ = height of the center of gravity at the highest point of the swing after the slider has passed over the test surface (as indicated by the pointer)

Equating the loss in energy to the work done and solving for $\mu$ gives:

$$\mu = \frac{W(H-h)}{DP}$$ \hspace{1cm} (3)

Thus, the coefficient of friction can be calculated in terms of the value of $H-h$ and the known constants of the instrument. For any given instrument, for a given value of $\mu$ there is a corresponding value of $h$ so that a scale can be marked on the instrument from which $\mu$ can be read directly.

The pendulum arm is suspended by a cantilever system in front of the supporting frame. The base plate of this frame is T-shaped with a leveling screw at the end of each arm. To prepare the instrument for test, the head of the pendulum carrying the swinging arm, the graduated scale and pointer, and the release mechanism is first unclamped and raised by means of the rack and pinion mechanism until the pendulum arm swings freely above the test surface. The base plate is then leveled so that the column of the apparatus and the scale are vertical. Next, the slider is raised a fixed distance from its stop by inserting a spacer underneath the setting screw on the lifting handle. The head is then lowered until, with the
pendulum hanging freely, the slider just touches the surface. The spacer is removed, and the sliding length is checked against a rule. The arm is then returned to the fixed horizontal position, prior to test.

The BPT has been found to demonstrate high accuracy of measurement and has been used extensively in laboratory skid resistance research and, to a limited extent, in field work. One drawback of the BPT, as is the case with all portable skid testers, is its insensitivity to the drainage properties of pavement surfaces and its inability to take account of the skid resistance speed gradients.16, 23, 27, 29

Data From Test

The test is performed by swinging the pendulum arm over the test surface twelve times, with the direction of swing the same as the direction of traffic. The results of the first swing and seventh swing are not recorded. The slider is reversed after the first six swings and the instrument is recalibrated. Ten values are recorded and averaged to give the mean BPN for the test surface.

Correlation of BPN values with full scale skidding machines has been achieved by a number of research agencies using a variety of field instruments.21, 27, 32, 33 In all instances, a correlation was found to exist between two sets of skid resistance values. However, in several instances to date, a wide confidence interval resulting, in part, from test site variations was noted. This led to the conclusion that "poor" correlations between full scale methods and the portable tester would prevail.21, 32 It is believed, however, that close control of field operations will reduce site variations and permit good correlations with small errors of estimate to be obtained.
11. REQUIREMENTS FOR SURFACE TEXTURE MEASURE

The friction coefficient between two sliding surfaces arises from:

1. Adhesion at the points where the surfaces are in contact (in the case of a wet road such contact implies that the lubricating layer of water on the road must have been broken through and areas of dry contact established), and

2. Irreversible deformation of one surface caused by irregularities on the other surface (this deformation can occur in the presence of a lubricant, and even if no actual contact between the surface is established). ¹⁴

The importance of the texture of a pavement surface and its influence on skid resistance have been stressed by several investigators¹³-¹⁵,³⁴-³⁶ and it is now recognized that a surface requires both sufficient roughness (macrotexture) and a sufficient harshness (microtexture) to be skid resistant. The rough texture is required to provide drainage channels to assist in the removal of the water under wet conditions and also to produce deformations of the tire. The ultimate penetration of the water film can be achieved only by the presence of fine scale asperities on which high contact pressures are developed.

Experience has shown that the value of the coefficient of friction between a vehicle tire and the pavement surface at 30 mph largely depends on the state of aggregate polish, i.e., the very fine scale texture of the surface, and not on the size of the easily visible asperities. On a wet surface, a high coefficient is obtained at 30 mph if the surface contains small
scale sharp edges as these assist the tire to break through the water film and establish areas of dry contact; in these circumstances, the adhesion component predominates. At 30 mph, it is the fine scale texture of the surface which is important, and large scale texture plays only a small part. The latter becomes important at higher speeds (80 mph) in cases where breakthrough of the water film is difficult to effect in the time available, and the friction generated is determined mainly by the deformation losses. However, the level of coefficient at 80 mph is not dependent solely on coarseness of texture.\textsuperscript{14}

Sabey\textsuperscript{14} has established that there is little correlation between the coefficient at 30 mph and texture depth established by the sand patch method. She further reports that although there is a more significant statistical correlation between the coefficient at 80 mph and texture depth, the amount of scatter is still extremely large.

A statistical correlation between the "texture depth" of the surface and the percentage decrease in coefficient between 30 and 80 mph has been established by Sabey.\textsuperscript{14} Although there was a large amount of scatter in the results, two conclusions were drawn from the relation. Very large decreases in coefficient between 30 and 80 mph can be expected when the texture depth is less than 0.010 in., however high the coefficient is at 30 mph. In order to restrict the decrease to 20 percent, texture depths greater than 0.025 in. are desirable.

Smithson\textsuperscript{13} recently reported the information plotted in Fig. 6. It is readily apparent that pavement texture significantly influences the coefficient of friction, especially at higher speeds.
Fig. 6 Influence of Vehicle Speed and Pavement Surface Texture on the Coefficient of Friction (After Smithson)
In a recent study performed by the Texas Highway Department (THD), some 500 wet weather accidents were studied and data collected on several vehicle and pavement variables. It was found that pavement macrotexture was one of the most significant contributors to the accidents studied. The data plotted in Fig. 7 are from the THD study. These data show that a very large percentage of accidents occur on pavement surfaces with small macrotexture values. With basis on the Texas study, a minimum texture of 0.5 in. per 27 in. (equivalent to approximately 0.035 in. by the sand patch method) is suggested for design purposes. At this value, the numbers of accidents have decreased to a constant level.

The previous discussion emphasized the influence and importance of texture on the skid resistance of a pavement surface. Although several methods exist for determining surface texture (see Appendix B), many of the methods have been shown to be unsatisfactory.

After conducting a thorough review of literature pertaining to existing surface texture measuring methods, the following requirements for a method of measuring the surface texture of pavement surfaces to be studied on Project IHR-406 were formulated. These requirements are not listed as to order of importance.

1. The method should be relatively simple to perform.
2. The method should not require more than one technician for conduct in the field.
3. If possible, the method should provide a permanent record of the surface at the time of texture determination.
Fig. 7 Influence of Pavement Surface Texture (Accumulative Peak Heights in 27 inches) on Number of Accident Sites

(After Morgan, et al.)
4. The method should not be new. Prior evidence of satisfactory use should exist.

5. The method should permit measurement of more than one textural parameter.

6. The results should correlate with the results of full scale testing machines such as the State skid trailer.

7. Use of the method in the field must present a minimum of hazard to both operator and traffic.

8. The method should permit rapid set up of equipment and minimize time required on the pavement surface.

9. The technique should be equally suited to all "types" of pavement surfaces.

10. The devise and procedure must be applicable for use in the laboratory on small size specimens and in the field.

11. The cost of the test equipment and the data reduction process should not be excessive.

12. The device must be capable of measuring surface texture at any location on the pavement surface.

13. The instrument should be relatively maintenance free.

14. Use of surface "contaminants" should not be required.

15. Highly reproducible results should be possible for a specific test surface at a given location.

16. Environmental factors should not influence test results.

17. The test procedure should be adaptable to standardization and should be acceptable to several engineers and researchers as a method of test.
12. STEREOPHOTOGRAPHIC METHOD FOR EVALUATING PAVEMENT SURFACE TEXTURE

General

The stereophotographic method for measuring pavement surface texture was first reported by Sabey and Lupton\textsuperscript{36} and then by Schonfeld.\textsuperscript{37} The method employs elementary principles of photogrammetry for vertical photography. The stereophotographic method has important advantages\textsuperscript{37} over other methods of measuring surface texture (sand patch and texture printing techniques) in that stereophotographs give a picture of both the size and shape of projections in the pavement surface.

The science of measurement of stereophotographs is based on the fact that sufficient information can be obtained from two photographs of an irregular surface to measure the heights of the irregularities of the surface. The photographs are taken from a camera pointing vertically downwards and from two points laterally displaced in a plane parallel to the pavement surface.

Apparatus

Stereopairs of photographs are taken by a single lens camera mounted in a box. Flash equipment for illuminating the surface is contained in the box and the angle of the flash is preset to give as uniform illumination of the surface as possible. A photograph of the apparatus is shown in Fig. 8.

Measurements of the parallax (displacement of an image due to two different points of view) are made with a stereocomparator. The procedure
Fig. 8 Box and Camera Device to Obtain Stereophotographs in University of Illinois Study
for making parallax measurements and for evaluation of other texture elements of the surface has been described by Schonfeld.37

Texture Code Number

Schonfeld\textsuperscript{51} had identified six groups of texture parameters as having a recognizable effect on the skid resistance of a pavement surface (see Appendix C). Each parameter group is given a numerical scale of shapes, sizes or degrees. The numbers on the scale are the individual parameters; the parameters at the lower end of a scale usually, but not always, make the smallest contribution to skid resistance. Seven parameters--one from each group--constitute a Texture Code Number of the pavement which describes and identifies a pavement texture as a whole.

The Texture Code Number is composed of the most prevalent parameters on the examined photographs. If another parameter is present in significant proportion, it is measured and recorded as a secondary parameter (e.g., the C parameter is recorded as 5/3 if\textsuperscript{6} the prevalent angularity is sharp edges and if the secondary angularity is round edges).

Procedure

Schonfeld's procedure\textsuperscript{51} for evaluation of textural parameters from stereophotographs is as follows:

1. Note Parameter B, which is the width of surface projections most prevalent in the photograph. Use a low magnification stereoscope.

2. Keep in mind that all other parameters taken (A, C, D, and E)
be those of the projection width B, which has been chosen as the most prevalent in Step 1.

3. Note Parameter D, which is the density of spacing of the surface projections. Use a low magnification stereoscope.

4. Note Parameter A, which is the most prevalent height of surface projects. Use high and low magnification.

5. Note Parameter C, which is the prevalent shape of surface projections. Use high and low magnification.

6. Note Parameter E, which is the fine texture of surface projections. Use high magnification.

7. Note Parameter F, which is the background texture. Use high magnification.

Application

The establishment of Texture Code Numbers of various pavement surfaces and correlation of the numbers with the State skid trailer skid coefficients permits a second means of establishing the skid resistance coefficient of laboratory and field surfaces. The influence of changes in textural parameters as a result of changing aggregate type or source can be preevaluated. Further, changes in a given surface as a function of wear and polishing can be documented and quantified. The information that is forthcoming can assist in aggregate preevaluation for use in skid resistant pavement surfaces.
13. CORRELATION OF BRITISH PENDULUM TESTER SKID NUMBERS WITH ILLINOIS SKID TRAILER VALUES

As a result of the data collection effort expended on IHR-406 during the summer of 1971, a limited amount of data was obtained which permitted (tentative) correlation of the British Pendulum Tester Skid Numbers with the Illinois Skid Trailer Values. To establish the desired correlation, it was necessary to choose some standard method for constructing the line that best approximates, or "fits" the observed trend. At least four basically different methods for obtaining a line of best fit can be employed. A brief review of these methods follow:

1. Major Axis. A line that minimized the sum of the squares of the perpendicular distances from each point to the desired line is called the major axis. In Fig. 9, this perpendicular distance is indicated by the distance, BF. Critical analysis of the properties of this line has shown that its slope changes with the unit of measurement.

2. Regression of $y$ on $x$. The regression of $y$ on $x$ is defined as the line that minimizes the sum of the squares of deviations from that line, the deviations being measured perpendicular to the $x$-axis ($x$ is taken as the independent, and $y$ as the dependent variable). In Fig. 9, this vertical distance corresponds to the distance $AE$. Regression analysis utilizes the assumption that all of the dispersion involved is due to deviations in one variate. For comparison of skid values
Fig. 9 Diagram to Show Various Methods of Fitting a Line to a Scatter of Points

NOTE: A regression line $y$ on $x$ minimizes the sum of the squares of the deviations measured as $AE$. A regression line $x$ on $y$ minimizes the corresponding sum of deviations measured as $DK$. A major axis minimizes the sum of the squares of the deviations measured as $BF$. A reduced major axis minimizes the sum of the areas of triangles $GCI$.

(After Imbrie)
obtained by two different methods of measurement, this assumption is not warranted, for variability and observational errors are involved in both variates.

3. **Regression of x on y.** The regression of x on y is defined as the line that minimizes the sum of the squares of the deviations from that line, the deviations being measured perpendicular to the y-axis. This horizontal distance is indicated in Fig. 9 as the distance, DK. Use of this line entails unwarranted assumptions of independence.

4. **Reduced Major Axis.** This line minimizes the sum of the areas of the triangles formed by lines drawn from each point to the desired line and parallel with the x and y axes. In Fig. 9, this area is equivalent to the triangle, GCI. The reduced major axis emerges as the best available statistical tool. To summarize some of the arguments for this line:
   a. It makes no assumptions of independence;
   b. It is invariant under change of scale;
   c. It is simple to compute; and
   d. Results obtained from its use are intuitively more reasonable than corresponding results obtained from regression analysis.

Accordingly, the reduced major axis technique was selected for establishing the desired correlations. Graphical plots of the two skid resistance values for four surface types are depicted in Figs. 10, 11, 12, and 13. For each surface type, the best fit line and the correlation
Fig. 10 Relationship Between British Pendulum Tester Number and State Skid Trailer Number for Class I Surfaces
Fig. 11 Relationship Between British Pendulum Tester Number and State Skid Trailer Number for Class B Surfaces
Fig. 12  Relationship Between British Pendulum Tester Number and State Skid Trailer Number for Class A Surfaces
coefficient were determined. This line is drawn on each graph. In addition, the best fit line and correlation coefficient for the total data set were established. All resulting information is tabulated in Table 1.

Observation of the information of Table 1 relates that excellent correlation exists for the two methods of determining skid resistance coefficients on bituminous surfaces \((r > 0.90)\). Greater variability is encountered on portland cement concrete pavement surfaces \((r = 0.80)\). Further, the relationships in Figs. 10, 11, 12 and 13 indicate that the British Pendulum Tester is very responsive to measuring the coefficient of surfaces of relatively high skid resistance \((0.50)\) and less responsive to surfaces that have had appreciable wear and polish such that surface microtexture has been removed.

Additional data are to be collected during the summer of 1972. These data may have an influence upon the correlations established to date. Therefore, the correlations depicted in Figs. 10, 11, 12, and 13, and the information tabulated in Table 1 must be regarded as tentative, subject to change.
Table 1

RESULTS FROM STATISTICAL ANALYSIS

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<td>1.5986</td>
</tr>
<tr>
<td>Class A</td>
<td>28</td>
<td>1.5690</td>
<td>-30.538</td>
<td>0.9254</td>
<td>1.6955</td>
<td>1.4520</td>
</tr>
<tr>
<td>Antiskid</td>
<td>4</td>
<td>1.6711</td>
<td>-50.350</td>
<td>0.7206</td>
<td>2.3189</td>
<td>1.2043</td>
</tr>
</tbody>
</table>
14. CALIBRATION OF BRITISH ACCELERATED WEAR AND POLISHING MACHINE

After acquisition of a British Accelerated Wear and Polishing Machine from England, the equipment was set up in Talbot Laboratory, University of Illinois, and calibrated. Required calibrations are described in British Standard 812:1967\(^2\)\(^6\). These include the "checks" of the following items:

1. Tire inflation pressure: 45 ± 2 psi
2. Free wheel rotation without play in the bearings
3. Planes of rotation of two wheels are parallel and center planes not more than 1/32 in. apart
4. Pneumatic tire speed: 315 - 325 rpm
5. Pneumatic tire wheel total load to specimen surface: 88 lbs
6. Rate of abrasive feed
   a. Coarse: 20 - 35 gm/min
   b. Fine: 2 - 4 gm/min
7. Water feed
   a. With coarse abrasive: 20 - 35 gm/min
   b. With fine abrasive: 4 - 8 gm/min
8. Temperature of room in which test conducted: 20 ± 5°C
9. Other checks involve mechanical operation, specimen mounting, safety protection and standard procedures during specimen preparation.
Once the equipment was checked out, trial wear and polishing tests of 6-hour duration were performed, first with cement mortar specimens and then with specimens prepared with Illinois aggregate (3/8 in. to No. 4). In addition, specimens prepared with a standard aggregate imported from England were subjected to testing.

The imported aggregate is a stone from Enderby Quarry, Leicestershire, England, and has been found suitable, by the Road Research Laboratory, for giving reasonably consistent results when different samples are subjected to the British wear and polish test. Expected results after the standard 6-hr test for this aggregate are of the order of 50 to 54 (Polished Stone Value). Use of the imported aggregate in trial test specimens allowed determination of whether or not the test procedures and equipment at the University of Illinois were satisfactory. Minor modifications in procedure were effected, as necessary, to produce reproducible results between laboratories.

After the equipment and testing procedure were checked out in the previously described manner, a testing program involving the aggregates used in the study sites (sites investigated in the summer of 1971) was established. This program is currently underway and results are being compiled for future detailed data analysis.
15. CORRELATION OF PHOTOINTERPRETED SKID NUMBERS WITH ILLINOIS SKID TRAILER VALUES

The Texture Code Number of field surfaces investigated on IHR-406 in the summer of 1971 is being established from stereophotographs taken at the time of field testing. To date, correlation of the resulting textural information with skid trailer skid coefficient values has not been attempted. This correlation will be performed as part of the data analysis portion of Phase 2 of the Project IHR-406 (see Appendix E).

Schonfeld has provided data which indicate that good correlation is to be expected. The data depicted in Fig. 14 were reported by Schonfeld for trailer test speeds of 30 and 60 mph. It is reasonable to assume that similar correlation will exist at the standard State of Illinois skid trailer test speed of 40 mph.

The applicability of Schonfeld's procedure is being investigated by the Project staff. Further, a Table of Friction Weights for the State of Illinois test speed of 40 mph is being developed, based on:

1. The data reported by Schonfeld for the 30 and 60 mph situations, and
2. The data collected on IHR-406 to date.

It is anticipated that reliable estimates of pavement surface skid resistance will be forthcoming from knowledge of textural parameters evaluated by use of the stereophotographic method.
Fig. 14a  Correlation Between Estimated Skid-Number and Skid-Trailer Skid-Number (30 mph)

Fig. 14b  Correlation Between Estimated Skid-Number and Skid-Trailer Skid-Number (60 mph)

(After Schonfeld)
16. SUMMARY AND CONCLUSIONS

The research effort for Phase 1 of Project IHR-406, "Aggregate Characteristics Affecting Skid Resistance," has been completed. Work on Phase 1 consisted of

1. A thorough review of the literature pertaining to skid resistance of pavement surfaces, with emphasis on the role and influence of the aggregate characteristics;

2. Development of requirements for testing equipment or procedures for measuring skid resistance, developing accelerated wear and polish and evaluating surface texture of laboratory and field surfaces; and

3. Selection, acquisition and calibration of testing equipment or procedures fulfilling the requirements previously established.

Each part of Phase 1 has been described in detail in this report.

The results of the research effort to date indicate that test procedures and equipment for pre-evaluation of aggregates in Illinois for use in skid resistant pavement surfaces exist. Data being obtained and correlated with the measured skid resistance of field surfaces (by the full scale trailer method) will be used to establish criteria for selection or rejection of aggregates in Illinois for use in surface courses. Assuming proper construction techniques and controls are followed during pavement construction, pavement surfaces that have a satisfactory initial coefficient of friction (wet) and that will maintain this level of resistance under traffic will result from application of the criteria and test procedures forthcoming from Project IHR-406.
The information compiled on Project IHR-406 will have substantial impact on the design and construction of pavement surfaces in Illinois and may be expected to influence pavement design and construction procedures throughout the country.
17. IMPLEMENTATION OF RESEARCH RESULTS

Successful conclusion of the research effort should lead to
1. Adoption by the Illinois Division of Highways (IDH) of a
   recommended method for preevaluation of the wear and polish
   resistance of an aggregate,
2. A recommended acceptance level for wear and polish resistance
   of an aggregate, and
3. Adoption of specifications covering requirements for aggregate
   for use in producing and maintaining skid resistant
   pavements, overlays and surface treatments in Illinois.

The information forthcoming from the study is being compiled into
project reports for use by the sponsoring agencies. In addition, pertinent
aspects of the findings will be developed into papers which, in turn, will
be submitted to technical associations for consideration for publication.
In this manner, the research findings will receive widespread distribution.

Further, the project personnel are working closely with personnel
from the Physical Research Laboratory of IDH. This contact permits research
findings to become known by IDH personnel shortly after attainment. Such
knowledge is influencing the research efforts of the Physical Research Labora-
tory.

Tentative specifications for skid resistant bridge decks in Illinois
are currently being developed by IDH personnel. Project IHR-406 staff are
assisting in the development of these specifications by providing input based
on data collected on the project to date.
Finally, recommendations for modifications to existing practice will be made, after extensive data analysis, to reflect the research findings. These recommendations will be reviewed by IDH personnel for implementation.
18. LIST OF REFERENCES


Appendix A

METHODS OF LABORATORY ACCELERATED WEAR AND POLISHING OF AGGREGATE AND MEASUREMENT OF SKID RESISTANCE

General

A review of the literature pertaining to accelerated wear and polishing of aggregate and measurement of skid resistance reveals that several test methods are in existence for producing wear and polish of aggregates and measuring skid resistance. A summary of methods in existence prior to 1960 is found in Ref. 3. Included in the summary are the following methods:

1. Purdue University Skid-Test Apparatus
2. University of Kentucky Method
3. University of Tennessee Equipment
4. National Crushed Stone Association Procedure
5. European Laboratory Test Methods
   a. British
   b. French
   c. Spanish

A brief description of each of these wear and polishing methods, excerpted from Ref. 3, is given below:

Purdue University Skid-Test Apparatus

One of the most extensive laboratory investigations was undertaken at Purdue University. "A laboratory skid-test apparatus which evaluates both laboratory specimens and cores taken from the highway, was developed to measure skid resistance.\textsuperscript{39,40} The apparatus spins a 6 in. diameter test specimen at a
constant speed of 2,500 rpm and evaluates the slipperiness of the specimen by forcing a rubber testing shoe against the surface of the specimen with a unit pressure of 28 psi. All tests are performed in the wet condition, and the amount of torque developed in the shaft supporting the testing shoe, caused by skidding of the shoe on the test specimen, is recorded as a measure of the wet-skid resistance of the specimen."

"A rather involved wearing and polishing procedure also was developed to simulate the effect of traffic. For bituminous mixtures the specimens were given an additional rolling or kneading cycle in order to accomplish the aggregate particle orientation that occurs at the surface of a bituminous pavement because of the action of traffic. Portland cement specimens were subjected to wear and polish only. Both portland cement and bituminous specimens, representing typical highway mixes, were evaluated for skid resistance, initially and after varying degrees of polish."

University of Kentucky Investigation

"A basic study of the polishing characteristics of limestone and sandstone in regard to pavement slipperiness was made at the University of Kentucky. Four-inch-diameter stone cores were used as the test specimens in this investigation and were ground down to their most slippery condition with 80 and 150 grit carborundum. A 60° reflectometer was used to evaluate texture and roughness of the polished surfaces. In addition, the skid resistance of the stone cores was obtained with a machine developed to measure the coefficient of friction between the surface of the stone and a sliding rubber annulus. Both wet and dry tests were performed."
University of Tennessee Equipment

"An interesting procedure for evaluating the potential slipperiness of paving mixtures has been developed at the University of Tennessee.\textsuperscript{42} The skid resistance of a test specimen is determined by the amount of power required to spin a standard passenger car tire at a constant speed as it rides upon the test surface. Less power is required to drive the tire on the more slippery surfaces. Standard test conditions call for a relative speed between tire and surface of 10 mph and a total load of 270 lb."

"The equipment is also used in wearing and polishing a test specimen. Spinning the tire on a fixed surface is equivalent to a continuous skid, and in a 24-hr. period considerable wear takes place. The test area is kept well lubricated to prevent overheating of the tire."

National Crushed Stone Association Procedure

"This organization has been active in investigating the antiskid characteristics of different paving mixtures, and while their published results are rather limited, the testing procedure is well defined.\textsuperscript{43,44} The slipperiness is evaluated by lowering a rotating bicycle tire onto the surface of a test specimen and measuring the angle through which the tire rotates in sliding to a stop. The slicker the surface, the greater the angle of rotation."

"The test specimens are polished in a 15 ft diameter test track, 18 in. wide. A standard bus tire rolls around the track and, because of the small radius of curvature, subjects the surface of the specimen to a twisting action in addition to rolling. This combined action rapidly results in the
particle orientation and degree of polish experienced because of prolonged exposure to heavy traffic and appears to be a realistic method of subjecting paving mixtures to accelerated wear."

European Laboratory Test Methods

"There are a variety of laboratory units that have been used in Europe to evaluate skid resistance, but very little has been published in the way of results. Both the British and French have devices for measuring slipperiness which are similar in principle to the Charpy pendulum. A rubber strip is attached to the head of the pendulum which, on being released, falls through a given arc, wipes across a test specimen, and, depending upon the degree of slipperiness of the surface, rises a measured amount on the other side. The slicker the surfaces, the greater the arc through which the pendulum will swing. This pendulum may be used either on the highway or in the laboratory."

"The Spanish have developed a rotating-wheel unit that is similar in some respects to the University of Tennessee equipment. A passenger car tire is caused to rotate at constant speed, while suspended immediately above the test surface. The tire is then lowered against the surface with a given pressure, and the rate of angular deceleration is determined. The higher the rate of deceleration, the greater the skidding resistance of the specimen. This unit also can evaluate slipperiness both on the highway and in the laboratory."

"A somewhat more fundamental approach has been that of the British Road Research Laboratory in their effort to measure texture of the surface. Their philosophy is that in order to obtain high resistance to sliding, the most important factor is that the projections in the road surface must have
sharp edges, whatever their size may be. In the laboratory apparatus designed to measure the edge effect, different stones of various shapes are made to slide, by means of compressed air, over a strip of wet rubber, and the frictional forces that result are recorded electrically."

Since 1960 additional methods have been developed. Several of these methods are listed and described below.


North Carolina State University Circular Track Wear Machine

A laboratory machine was designed and built at North Carolina State University for the polishing of pavement samples made from selected aggregates.16 A circular 6 in. diameter specimen is used in the wear and polishing machine. The machine consists of a small circular test track where pavement specimens are worn and polished under the action of pneumatic tires. Four tires rotate around the 36-in. diameter track at the rate of 30 rpm, generating 7,200 tire-passes per hour, or one million tire passes in just under six days. The passage of the tires induces wear and polish to each pavement specimen in the same manner, but the extent of wear and polish imparted is dependent upon the properties of the specimen. To establish skid resistance level, a track segment is removed from the machine for British Pendulum Tester (BPT) measurements and replaced to continue wear and polishing exposure.

To obtain accelerated machine polishing action, an adjustment on the tire set-up is introduced whereby two of the diametrically opposed
wheels toe-in while the other tow toe-out half a degree producing a scrubbing and wiping tire action in addition to a rolling action. The tires used in the machine have 11-1/4 in. diameter, 3.5 in. tread width, and no tread. No abrasive is introduced at the tire-surface interface during the test.

North Carolina State University Jar Mill Wear Machine

It may be reasoned that if samples of aggregate are subjected to any reasonably gradual method of wearing and polishing of the individual aggregates, the polished particles should, when tested, reflect the skid resistance characteristics of the particular aggregate they represent. At North Carolina State University a laboratory jar mill utilizing porcelain jars was used to achieve the gradual wearing and polishing of aggregate samples.16

In this method, heavily glazed, tough-bodied porcelain jars, each having an inside diameter of approximately 9.0 in., a clear depth of 8.5 in., and a mouth opening diameter of 5.0 in. are charged with 1000 grams of aggregate and another 1000 grams of 3/4 in. size flint pebbles used as an abrasive charge. The aggregate size is selected to be of the passing 3/8 in. retained on the No. 4 sieve size.

After charging, the jar is placed on its side on the rollers of the jar mill. The number of revolutions of the rollers is maintained at a speed of 52 rpm through the testing, for a period of 24 hours. At the end of a wearing cycle, the worn material from the sample is carefully poured into a thoroughly cleaned and individually pre-weighed set of nested standard sieves (3/8 in. and Nos. 4, 8, 16, 30, 50, 100, and 200.) The
aggregate weight retained on each sieve is determined. Next, the aggregate retained on the No. 4 sieve is thoroughly washed and dried in the oven for 12 to 24 hours and the aggregate dry weight calculated. The loss in grams of the weight of dry aggregate retained on the No. 4 sieve (divided by 1000 grams) is used to determine jar mill percentage wear loss.

British Accelerated Wear and Polishing Apparatus

The British Accelerated Wear and Polishing Apparatus\textsuperscript{26} was selected for use on Project IHR 406. The apparatus and testing procedure has been previously described in detail in Section VIII of this report. Accordingly, a description of the apparatus and testing procedure is not repeated in this Appendix.
Appendix B

METHODS FOR MEASURING PAVEMENT SURFACE TEXTURE

The "topography" or surface texture of a pavement surface influences the skid resistance of the surface. Several methods for measuring surface texture have been developed and attempts have been made to correlate pavement texture and skid resistance. The following methods are among those reported in the literature for surface texture determination.

1. The Sand Patch Method.⁴⁶ In this method a known quantity of fine sand is spread on the pavement surface until the surface interstices are just filled level with the tops of the surface asperities. The area of the sand patch is measured and divided into the volume of sand used. The result of the computation is said to be the "texture depth."

2. The Print Method.⁴⁷ This method imprints the image of the pavement's bearing surface on a sheet of paper and also gives some indication of length and width of surface drainage channels.

3. The Mould Method.⁴⁶ This method uses hardening plastics or plaster of Paris to replicate the pavement surface texture which can be used a) directly for surface measurements in the laboratory or b) used to obtain photographic enlargements from which measurements can be made.

4. Multiple Sounding Needles.⁴⁶ Multiple sounding needles (e.g., Reinhart Text-ur-meter) which are free to move vertically and rest on the pavement surface, define a series of points representing the texture profile.
5. The Outflow Meter. A meter utilizing water measures directly the mean hydraulic radius of the surface texture of a surface. Measurement of size of texture is made by observing the time of efflux required for a certain quantity of water to flow from a vessel, with rubber ring in contact with the surface, between the rubber and the surface voids.

6. The Single Sounding Needle. This method combined with an electronic device, has been used for drawing a texture profile. Surface profiles are obtained and a theoretical value of the mean hydraulic radius of the surface is established from measurements made with a planimeter and an opsiometer.

7. Reflectometer Method. A 60 degree reflectometer has been used in a University of Kentucky investigation to evaluate texture and roughness of polished surfaces.

8. Indiana Method. This method utilizes a light proof box with an open bottom across which a thin wire is stretched. A camera mounted on the side of the box photographs the wire and its shadow when a strobe light on top flashes. The surface profile at the wire is measured from photographic enlargements as the distance from wire shadow to surface.

9. Road Research Laboratory Method. On the assumption that a pavement surface must contain particles with sharp edges to obtain high skid resistance, a laboratory procedure was designed to measure aggregate edge effect. Aggregates of various shapes are made to slide, by means of compressed air,
over a strip of wet rubber, and the frictional forces that result are recorded electrically.

10. *Ontario Photo-Interpretation Method.*

This method entails classification of pavement surfaces by describing the surface characteristics of a small section of the pavement based on stereo photographic reproductions. The geometric shapes, sized and microtexture of seven topographical features are examined and a "Texture Code Number" for the surface is determined (see Section XII).

11. *Grease Smear.*

This NASA method is similar to the Sand Patch method except grease is used instead of sand.
Appendix C

TEXTURE PARAMETERS OBSERVED IN STEREO PHOTOGRAPHS

Seven groups of texture parameters identified by Schonfeld\textsuperscript{37} as a direct effect on the skid resistance of a pavement surface are presented in this appendix. Each parameter group has been given a numerical scale of shapes, sizes, or degrees. The numbers of the scale are the individual parameters; the parameters at the lower end of a scale usually, but not always, make the smallest contribution to skid resistance. Seven parameters--one from each group--constitute a Texture Code Number of the pavement which describes and identifies a pavement texture as a whole. Each element of texture has its own scale of sizes. A summary of the information contained in this appendix is given in Table 2.

**Height Parameter A** is measured in millimeters from the top of the background to the top of the projection.

<table>
<thead>
<tr>
<th>Scale:</th>
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</thead>
<tbody>
<tr>
<td>A0</td>
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<tr>
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<td>A3</td>
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<td>A4</td>
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<td>A5</td>
</tr>
<tr>
<td>A6</td>
</tr>
<tr>
<td>A7</td>
</tr>
</tbody>
</table>

**Width Parameter B** is measured in millimeters and is the horizontal dimension of the projection. It is measured at the level of the top of the background.

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</thead>
<tbody>
<tr>
<td>B0</td>
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<td>B2</td>
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<tr>
<td>B3</td>
</tr>
<tr>
<td>B4</td>
</tr>
<tr>
<td>B5</td>
</tr>
</tbody>
</table>
Angularity Parameter C describes the edges of the projections which may come in contact with the tire.

Density of Spacing, Parameter D is estimated as one would estimate the proportion of occupied seats in an auditorium: empty (0), one-quarter full (1), half-full (2), three-quarter full (3), full house (4).

Scale:
- D0: No Asperities
- D1: Asperities take up about 25 percent of total area
- D2: Asperities take up about 50 percent of total area
- D3: Asperities take up about 75 percent of total area
- D4: Asperities take up about 100 percent of total area
Fine Texture of Projections Parameter E denotes size, sharpness or roundness of the micro-projections on the surface of the stones.

1. SHINY, POLISHED SURFACE OF STONE

2. MAT. SMOOTH SURFACE OF STONE

3. FINE GRAINED (NOT GREATER THAN 1/4 mm) SURFACE OF STONE

4. STONE SURFACE HAS ROUNDED MICRO-PROJECTIONS, APPR. 1/2 mm HIGH, (PEBBLED MICRO-TEXTURE)

5. STONE SURFACE HAS ROUNDED MICRO-PROJECTIONS, APPR. 1 mm HIGH, (PEBBLED MICRO-TEXTURE)

6. STONE SURFACE HAS ROUNDED MICRO-PROJECTIONS, APPR. 2 mm HIGH, (PEBBLED MICRO-TEXTURE)

7. STONE SURFACE HAS SHARP MICRO-PROJECTIONS, APPR. 1/2 mm HIGH, (HARSH MICRO-TEXTURE)

8. STONE SURFACE HAS SHARP MICRO-PROJECTIONS, APPR. 1 mm HIGH, (HARSH MICRO-TEXTURE)

9. STONE SURFACE HAS SHARP MICRO-PROJECTIONS, APPR. 2 mm HIGH, (HARSH MICRO-TEXTURE)

Scale:

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<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>Polished Micro Texture</td>
<td>0 mm</td>
</tr>
<tr>
<td>E2</td>
<td>Smooth Micro Texture</td>
<td>0 mm</td>
</tr>
<tr>
<td>E3</td>
<td>Fine Grained Micro Texture</td>
<td>≤ 1/4 mm</td>
</tr>
<tr>
<td>E4</td>
<td>Pebbled, Rounded Micro Texture</td>
<td>≥ 1/4 mm</td>
</tr>
<tr>
<td>E5</td>
<td>Pebbled, Rounded Micro Texture</td>
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</tr>
<tr>
<td>E6</td>
<td>Pebbled, Rounded Micro Texture</td>
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</tr>
<tr>
<td>E7</td>
<td>Sharp, Harsh Micro Texture</td>
<td>1/2 mm</td>
</tr>
<tr>
<td>E8</td>
<td>Sharp, Harsh Micro Texture</td>
<td>1 mm</td>
</tr>
<tr>
<td>E9</td>
<td>Sharp, Harsh Micro Texture</td>
<td>2 mm</td>
</tr>
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</table>
Fine Texture of Background Parameter F denotes size, sharpness or roundness of the micro-projections in the background.

1. Shiny, polished surface of background

2. Mat, smooth surface of background

3. Fine grained (not greater than ¼ mm) surface of background

4. Background has rounded micro-projections, appr. ½ mm high, (pebbled micro-texture)

5. Background has rounded micro-projections, appr. 1 mm high, (pebbled micro-texture)

6. Background has rounded micro-projections, appr. 2 mm high, (pebbled micro-texture)

7. Background has sharp micro-projections, appr. ½ mm high, (harsh micro-texture)

8. Background has sharp micro-projections, appr. 1 mm high, (harsh micro-texture)

9. Background has sharp micro-projections, appr. 2 mm high, (harsh micro-texture)

Scale:

F1 Polished Micro Texture 0 mm.
F2 Smooth Micro Texture 0 mm.
F3 Fine Grained Micro Texture not greater than ¼ mm.
F4 Pebbled Rounded Micro Texture about ¼ mm.
F5 Pebbled, Rounded Micro Texture 1 mm.
F6 Pebbled, Rounded Micro Texture 2 mm.
F7 Sharp, Harsh Micro Texture ½ mm.
F8 Sharp, Harsh Micro Texture 1 mm.
F9 Sharp, Harsh Micro Texture 2 mm.
Table 2

TEXTURE PARAMETER FORM

<table>
<thead>
<tr>
<th>PARAMETER NUMBER</th>
<th>A HEIGHT mm.</th>
<th>B WIDTH mm.</th>
<th>C ANGULARITY</th>
<th>D DENSITY PERCENT</th>
<th>E FINE TEXTURE ANGULARITY AND HEIGHT mm.</th>
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<tr>
<td>0</td>
<td>0</td>
<td>&gt;16</td>
<td>FLAT</td>
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<td></td>
</tr>
<tr>
<td>1</td>
<td>1¼</td>
<td>8</td>
<td>ROUND</td>
<td>25</td>
<td>POLISHED 0</td>
</tr>
<tr>
<td>2</td>
<td>¾</td>
<td>4</td>
<td>SUBANGULAR PLATEAU</td>
<td>50</td>
<td>SMOOTH 0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>2</td>
<td>SUBANGULAR GABLE</td>
<td>75</td>
<td>FINE GRAINED 0</td>
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<tr>
<td>4</td>
<td>2</td>
<td>1</td>
<td>ANGULAR PLATEAU</td>
<td>100</td>
<td>ROUND ¾</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>½</td>
<td>ANGULAR GABLE</td>
<td>-</td>
<td>ROUND 1</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>-</td>
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<td>7</td>
<td>16</td>
<td>-</td>
<td>-</td>
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</table>

(After Schonfeld)
Appendix D

LIST OF PERSONS INVOLVED WITH PROJECT IHR-406
AGGREGATE CHARACTERISTICS AFFECTING SKID RESISTANCE

Illinois Division of Highways:

John E. Burke    Engineer of Research and Development
Robert F. Appleman  Field Engineer
Robert B. Dellert   Liaison Engineer
John H. Kane       Maintenance Planning Engineer
Richard M. Kiel    Liaison Engineer
Kenneth R. Keene  Assistant Engineer of Materials
Donald R. Schwartz Assistant Engineer of Research and Development
Larry J. Shoudel   Traffic Field Engineer
Donald L. Wolaver  Assistant Engineer of Roads, Plans
                    and Contracts

Federal Highway Administration:

John W. Breitweiser Area Engineer

University of Illinois:

Ellis Danner      Professor
Ernest J. Barenberg Professor
Don U. Deere      Professor
Moreland Herrin   Professor
Clyde E. Kesler   Professor
Richard L. Berger Associate Professor
Charles R. Marek  Assistant Professor (Principal Investigator)
Peter Tarkoy      Research Assistant
C. Robert Ullrich Research Assistant
# Aggregate Characteristics Affecting Skid Resistance

## Phases

### Phase 1: Testing Devices
1. Requirements for device(s)
2. Requirements for surface texture & skid resistance measure
3. Accelerated wear (calibration)
4. Surface texture (calibration)
5. Report

### Phase 2: Aggregate Characteristics
1. Data review and collection
2. Petrographic analysis
3. Laboratory testing
4. Data analysis
5. Criteria
6. Report
   a. Preparation
   b. Review
7. Final Summary Report
   a. Preparation
   b. Review

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<th>1973</th>
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<tr>
<td>1. Requirements for device(s)</td>
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<td></td>
</tr>
<tr>
<td>1.2 Requirements for surface texture &amp; skid resistance measure</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1.3 Accelerated wear (calibration)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1.4 Surface texture (calibration)</td>
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