SKIDDING ON HIGHWAYS

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TABLE OF CONTENTS

INTRODUCTION

Current estimates based on the highway accident records indicate that skidding by at least one of the involved vehicles occurs in over six per cent of all traffic accidents (25). Skidding was reported as involved in four out of ten (41 per cent) rural accidents in Virginia in 1957. In great Britain in 1957, records indicate that one out of four (27 per cent) personal injury accidents on wet road surfaces involved skidding--while on icy surfaces the proportion was four out of five (82 per cent). On the Pennsylvania Turnpike in 1952-'53, nearly one out of four accidents (22 per cent) involved failure of the driver to cope with road conditions. Most of these accidents involved skidding (11). Skidding is an important factor in highway accidents--indeed, far more serious a factor than is generally realized. Not only is the general public uninformed, but there is evidence that all too many highway administrators, engineers, other officials and even traffic and safety specialists are inadequately informed. In the United States of America, skid accidents data are not available in most states. Accidents mainly due to skidding increase significantly when the coefficient of friction between the sliding tire and pavement surface is less than 0.40. The wet skid factor becomes more serious as speeds increase and the traction coefficient decreases sharply. Currently there is an appreciable mileage of highways in the United States which cannot develop this friction value for all surface conditions, and as the polishing effect of traffic becomes increasingly intensified the mileage of slippery pavement will tend to increase. All highway surfaces can develop adequate skid resistance in the dry state. In fact all surfaces which are extremely slippery when wet exhibit excellent antiskid characteristics in the dry condition. The majority of the pavement surfaces, however, will frequently be exposed to rainfall, and it is in this wet state that a tremendous variability in the skid resistance of pavements occurs. Some surface types exhibit nearly as good antiskid characteristics when wet as when dry, while other surfaces can develop less than one fifth of the skid resistance in the wet state as compared with the dry.

PURPOSE

The purpose of this report is to describe and discuss

1. Skidding phenomena on roads

   A. General
   B. The relationship of vehicle dynamics to skidding
   C. The relationship of design and composition of tires to skidding
   D. The relationship of road surface properties to skidding
   E. Accidents and the human element in skidding

2. The measurement of skid resistance by different field and laboratory methods

3. The effect of aggregate factors on pavement friction

4. Polishing characteristics of mineral aggregates in regard to pavement slipperiness

5. Minimizing pavement slipperiness in new construction and

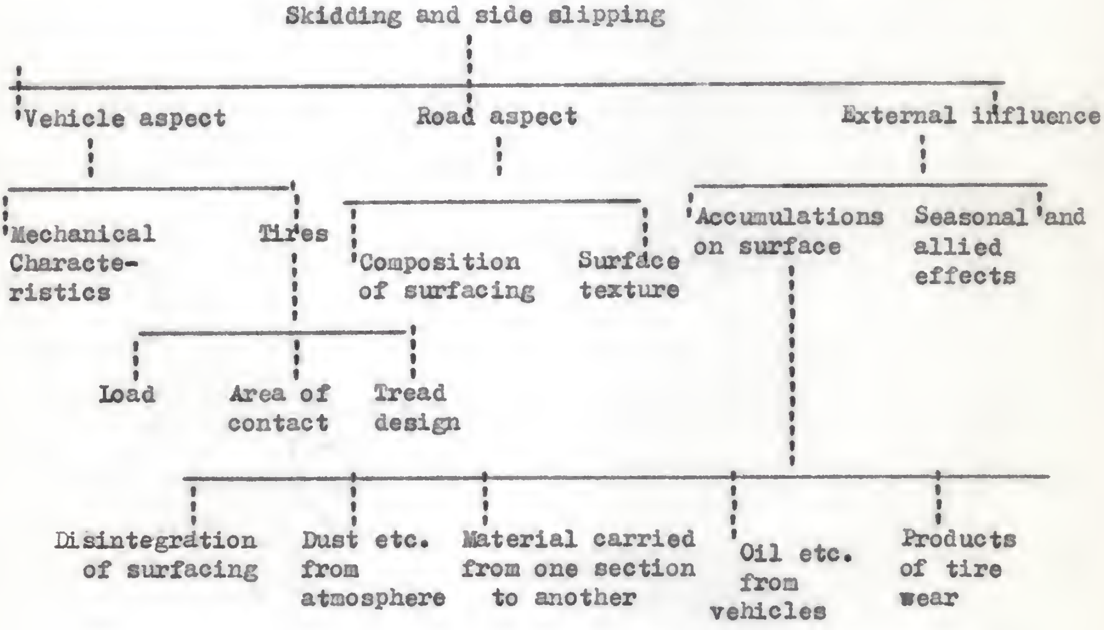
6. Improving the antiskid properties of slippery pavements.

SKIDDING PHENOMENA

General

The forces that are developed between a sliding rubber tire and a pavement surface illustrate some of the factors contributing to pavement slipperiness and also give an idea of the possible remedies for minimizing the effects of these factors.

According to Road Research Board, Great Britain (4), skidding and side slipping has been clearly subdivided as shown below.



GENERAL PROGRAM OF WORK ON SKIDDING

There are three important factors concerned with skidding; 1. vehicle, 2. road and 3. external influences. According to Moyer (4), the actual process of skidding is of three distinct types; 1. straight skidding in the direction of travel with the wheel locked such as is caused by a sudden application of brakes, 2. impending skidding which is encountered when the braking is gradual and the wheels are still revolving this being a modified form of straight skidding, and 3. sideways skidding, a form frequently occurring on curves which have not sufficient super-elevation to provide for the speed at which the vehicle is travelling or on tangents when cars are changing direction.

Engineers who have conducted tests find that in some instances pavements which are quite adequate structurally may, when subjected to a heavy volume of traffic for only a relatively few months, become dangerously slippery when wet. All such tests often reveal a wide range in the coefficient of friction of pavements attributable to various construction materials and road surface textures.

Relationship of vehicle dynamics to skidding

Many of the problems of vehicle dynamics related to the skidding problem are associated with tire brake behavior. For this reason many aspects of tire behavior relate to the dynamics of the tire road system are studied by automotive engineers. According to the reports of the sub-committee on the relationship of vehicle dyaamics to skidding to the First International Skid Prevention Conference, the gaps in our knowledge are as follow (18).

1. Tire efficiencies: Tire efficiencies are reasonably well established under normal conditions in the transmission of braking driving and steering forces and combinations thereof, but little is known about efficiencies under extreme conditions of steering and braking. Since these were the conditions of particular interest to this conference the deficiency in knowledge must be regarded as a gap.

2. Effect of unbalanced braking on skidding: There are data on the effect of unbalanced braking, front and rear, on skidding of a vehicle, but little data have been shown on the effect of unbalance in braking on the right and left sides.

3. Dynamic behavior of suspension systems on brake balance: Little is known about the behavior of suspension systems with regard to changes in brake balance and the resulting influence on skidding.

4. Differential design: Little data are available on the influence of differential design on skidding. As an example there are few quantitative measurements on record of the effect of the general class of locked differentials and on the variations of locking design.

Relationship of design and composition of tires to skidding

The function of a tire is complex and the requirements may be diametrically opposed. The total tire design must affect a compromise of control, stability, comfort, noise, skid resistance and tread wear characteristics meeting the majority of driving requirements.

The effect of tread design: The tread design of a tire is very important in influencing its resistance to skidding on most common road surfaces when they are wet. The elements of an anti-skid design which contribute to its skidding resistance or increase the coefficient of friction on wet surfaces are the following:

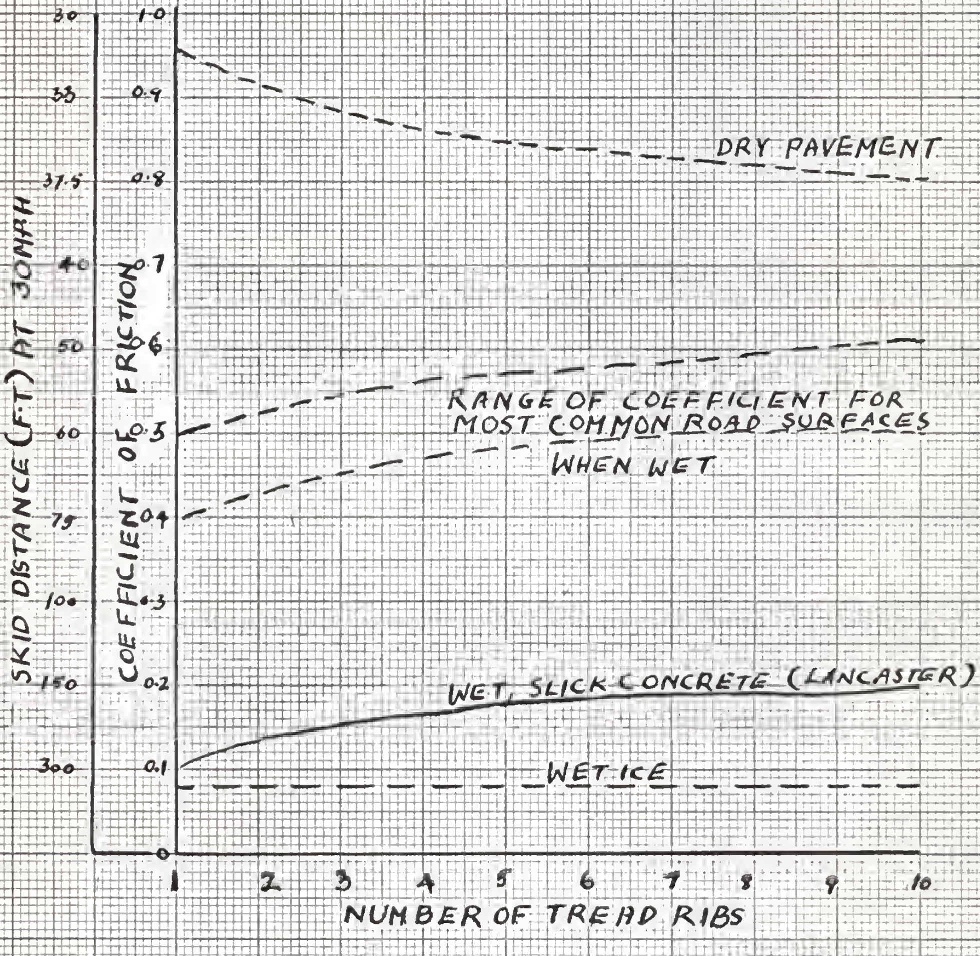
Grooves: They provide a venting or void to which the fluid at the interface of the tire and the road can be displaced by the pressure between them. Circumferential grooves can improve the skid resistance from 20 to 100 per cent on wet surfaces depending on its coefficient (19).

Edges: These provide a wiping action over wet road surfaces and more effectively remove the fluid between them and the tire. On extremely low coefficient road surfaces the effect of the wiping action of the edges made with molded slots and cut slits can improve skid resistance upto 100 per cent. For most road surfaces in the range of coefficient 0.4 to 0.5 the improvement is 20 to 25 per cent (19).

The tire industry has made a very marked improvement in skid resistance on wet pavements in recent years by the use of highly slotted anti-skid designs. This is acquired by tread compound improvements which increase the resistance and permit the same highly slotted tire to be driven at turnpike speeds for long periods of time without failure. The extent to which the design features influence the resistance to skidding is summarized in figures 1 and 2 from the report of the sub-committee on factors in tires that influence skid resistance to the First International Skid Prevention Conference, September 9, 1958 (19).

There are a few harsh, abrasive surfaces for which a smooth tread tire will generate equal or even greater, wet-skid resistance than a tire with a conventional tread pattern. For the majority of surface types, however, a tire with a good tread pattern will exhibit better resistance to skidding than one with a smooth tread, and for some dangerously slippery pavements, this advantage is appreciable.

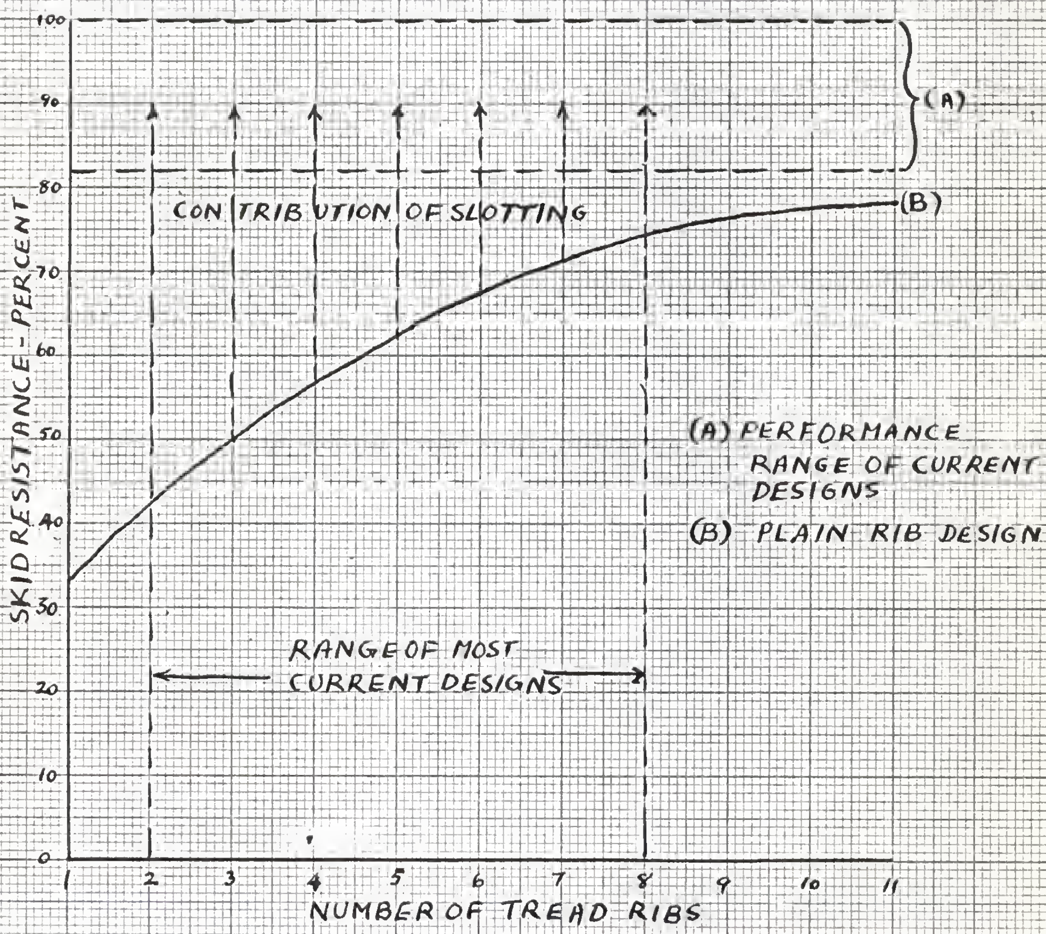
As the tire gets worn out there is rapid loss of skid resistance on wet surfaces. Figure 3 from the report of the sub-committee on factors in tires that influence skid resistance to the First International Skid Prevention Conference, September 9, 1958 (19), shows the loss of skid resistance with decreasing anti-skid depth. On the extremely low coefficient surface of wet ice it is found that the edges provided by grooves, slots or slits are effective to approximately 20 to 25 per cent. In the case of a dry pavement the most effective tire is the one having the largest net contact area with the road, that is the worn out tire. Grooves or slots, in general, provide edges which tear or decompose with high temperatures developed at the interface in dry skidding and this action diminishes the resistance to skidding (19).



COEFFICIENT VS NUMBER OF TREAD RIBS
HIGHWAY-TYPE PASSANGER TIRES, COMPARISONS AT 30M.P.H.

EXTRACT FROM "RELATIONSHIP OF TIRE DESIGN AND COMPOSITION TO SKIDDING" HIGHWAY RESEARCH BOARD BULLETIN 219 P.P. 15-24 (1959)

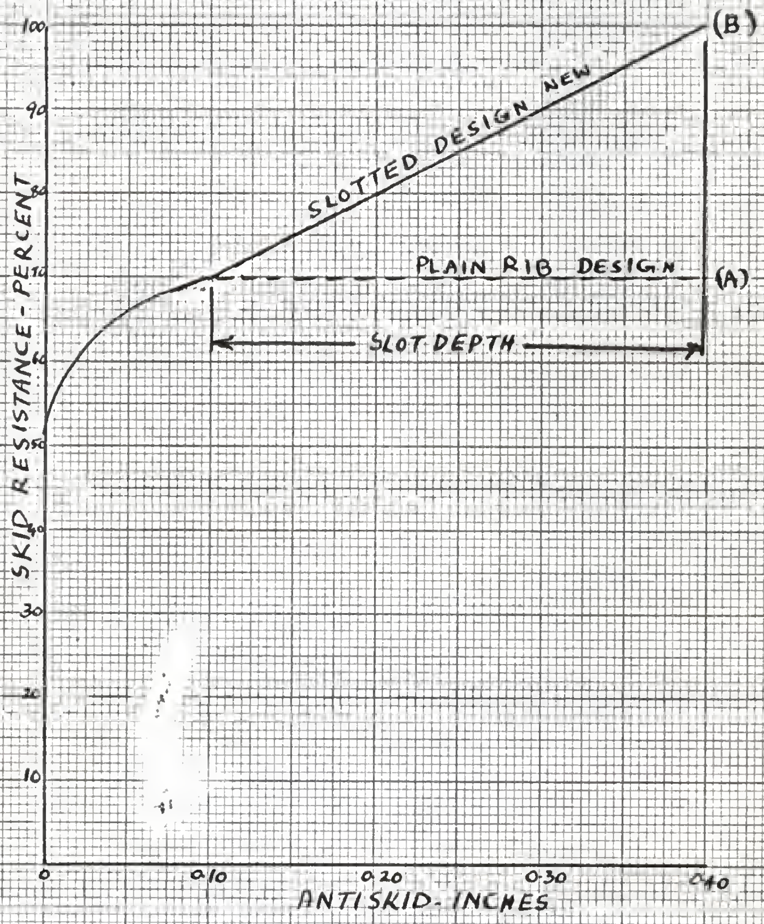
FIGURE 1



SKID RESISTANCE OF PASSENGER TIRES; EFFECT OF TREAD RIBS COMBINED WITH SLOTTING, WET SLICK CONCRETE (LANCASTER TEST SURFACE).

EXTRACT FROM "RELATIONSHIP OF TIRE DESIGN AND COMPOSITION TO SKIDDING", HIGHWAY RESEARCH BOARD BULLETIN 219 PP 15-24 (1959).

FIGURE 2



SKID RESISTANCE Vs ANTI-SKID DEPTH;
WET SLICK CONCRETE (LANCASTER TEST SURFACE)

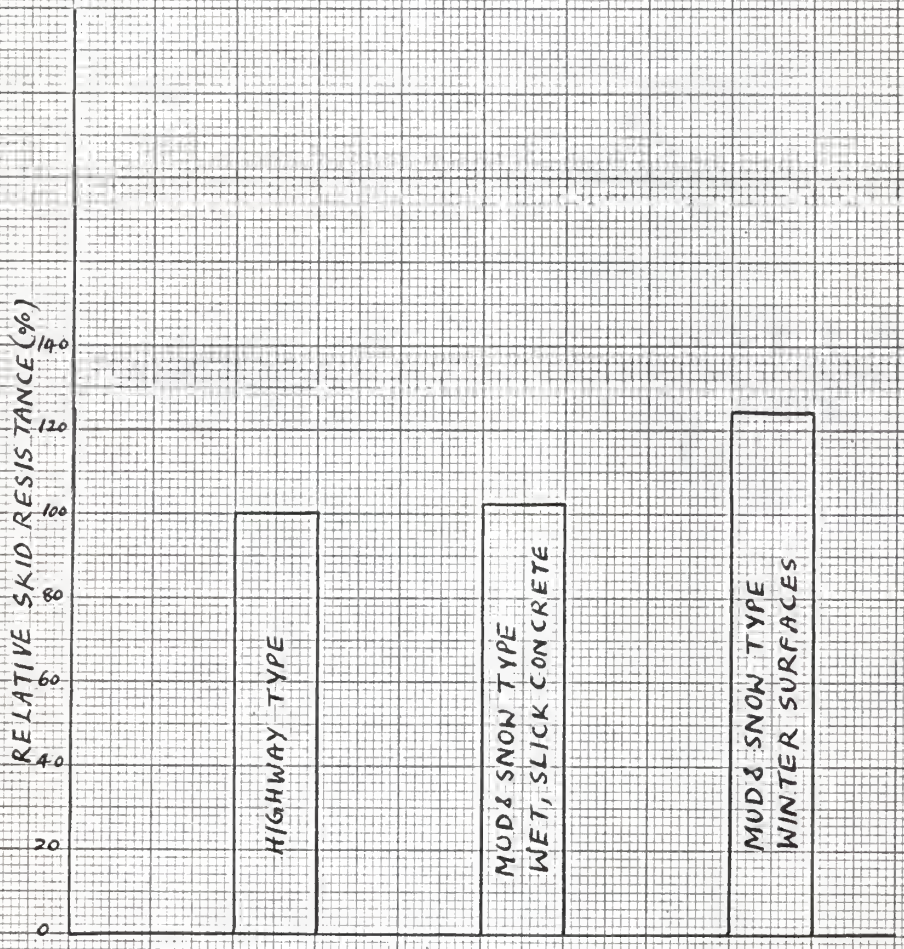
EXTRACT FROM "RELATIONSHIP OF TIRE DESIGN AND COMPOSITION TO SKIDDING", HIGHWAY RESEARCH BOARD BULLETIN 219 P.P 15-24 (1959)

FIGURE 3

Modern mud and snow tires provide an improvement of the order of 25 per cent in skid resistance on winter surfaces over present conventional highway types of tires, utilizing the maximum edges, grooves and slots--but at the sacrifice of tread wear. The comparison between the performance of highway and snow type is shown in figure 4 from the report of sub-committee on factors in tires that influence skid resistance to the First International Skid Prevention Conference, September 9, 1958 (19).

The effect of Carcass construction and Tire size: The data shows the effect of carcass construction features such as cord angle, number of piles; also tire size, does not have a significant effect on skid resistance (19).

The effect of Tread composition: The effect of tread composition on skid resistance is very important. However, of equal importance are wear resistance and weathering, ozone, deterioration and cracking resistance; and low heat build up, good ride, low noise, stability etc. Almost without exception, compound alterations which improve one or more of the essential service characteristics adversely affect the others. Further, a compound giving the best skid resistance onc dry pavement may not be satisfactory for wet surfaces on ice and snow. The superior skid resistance of GRS synthetic rubber, which is now the standard in all U.S.A. passenger tread compounds, is well established--especially in high speed, locked wheel panic stops on dry surfaces. This is primarily due to the fact that GRS's initial melting point



RELATIVE SKID RESISTANCE; MUD AND SNOW Vs HIGHWAY-TYPE PASSANGER TIRES

EXTRACT FROM "RELATIONSHIP OF TIRE DESIGN AND COMPOSITION TO SKIDDING", HIGHWAY RESEARCH BOARD BULLETIN 219 PP 15-24 (1959)

FIGURE 4.

is about 100° higher than natural rubber (19).

Effect of Load, Inflation and Speed: The load and inflation affect the coefficient of friction, but the effect is relatively minor.

Speed and application of power, factors entirely under control of the driver, create forces of enormous magnitude. Even under the best possible dry road conditions, the tire-road surface reaction may be insufficient for vehicle control. Certainly on low friction surfaces the available tire-road forces can easily become entirely inadequate. Under such conditions, there is no choice but for the driver to reduce speed and power factors into a range of safe vehicle control (19).

The following are the needs in this field as per the report of the sub-committee on factors in tires that influence skid resistance to the First International Skid Prevention Conference, September 9, 1958 (19).

1. A standard skid test tire is necessary to develop and correlate road surface friction measurements.

2. Strictly controlled studies will have to be undertaken to assure that a given type of standard skid test tire will give reproducible measurements on each type of surface friction measuring device and will produce accurate correlations.

Relationship of Road Surface Properties to Skidding

It is generally admitted that under dry conditions modern road surfaces are all reasonably skid-proof, but under alternating wet and dry conditions lead to false sense of security in the driver. The tendency for a vehicle to skid will largely depend upon the grip or friction between the tires of the vehicle and the surface with which it is in contact. The existing knowledge in this field as per the report of the sub-committee D to the First International Skid Prevention Conference, University of Virginia, Charlottesville, Virginia, September 8-12, 1958 is as follows (20).

1. Pavements of all types are much more slippery when wet than when dry. The skidding hazard is greatest during the first few minutes of rainfall following a period of dry weather, while after a continued downpour the slipperiness is greately reduced.

2. Many road surface factors affect skid resistance, including surface condition, surface construction type, surface maintenance, type of aggregate, cement or binder, surface texture, road roughness, foreign material, and surface contamination, water, surface scouring, age weathering and climatic effects, time effects, temperature, traffic and highway design.

3. The effect of surface texture on flexible pavements was the subject of some disagreement. Although no one denied the hazard of a smooth texture caused by an excess of bitumen in contact with the tire,

the relative merits of coarse and fine texture as related to aggregate size were still in debate. Several cited the advantage of a coarse, open texture on which surface water can drain away rapidly; this type of texture was described by some as "nobby". However, other data indicate that the highest coefficients of friction may be obtained on pavements constructed of very fine aggregate, the greatest proportion of which may pass a no. 40 sieve. Even sheet asphalts with around ten per cent asphalt binder and twelve per cent aggregate passing the no. 200 sieve have been reported to have very satisfactory skid resistance.

4. It is well recognized that rounded aggregates and the presence of an excess of asphalt are common causes of slipperiness. However, the polishing of certain types of aggregate used in surface construction is rather generally believed to be the principal cause of pavement slipperiness in most places of the United States. Cases have been reported where even "nobby" textured surfaces built of such aggregates have become extremely slippery as a result of the polishing action of rubber tired traffic.

5. On multi-lane surfaces, the driving lane generally is appreciably more slippery than the passing lane. This is due to the polishing action of greater traffic and in part to the greater accumulation of oil films.

6. Almost all aggregates will become polished under intense traffic, some, however, much sooner than others. Certain sand stones and gneisses are said not to polish in the laboratory. The softer

stones generally polish sooner than the harder stones. However, in service, many roads built with the softer stones have not polished sufficiently to cause slipperiness, their skid resistance is adequate for the traffic conditions.

7. Work in Europe, both in England and the Netherlands, has indicated that the skid resistance depends partly on the deformations of the rubber due to projections in the surface. Apparently for the best results, individual particles in the road surface should have angles at their tips of ninety degrees or less.

8. On ice, the most hazardous condition exists at temperatures near the freezing point. Thus at -30°F the bare tire skid distance is around 80 feet, but at +35°F it is 250 feet. It is found that tire chains are most beneficial under the severest conditions. Special tires are effective 85 to 90 per cent of the winter period. But no matter what may be the tire equipment, speeds should be considerably reduced when driving on ice and snow. Snow tires and tire chains are apt to give a false sense of security. Reduction in speed is highly important.

9. The geometric design of pavements is dependant on the fractional resistance between the tires and the road surface. The friction coefficients suggested are as follows.

(a) Maximum side friction factors ranging from 0.16 at 30 mph to 0.12 at seventy mph are used with practical super-elevation slopes to determine minimum safe radii of horizontal curves for open highway conditions.

(b) For intersection curves where design speeds are less than fifty mph maximum side friction factors ranging from 0.32 at 15 mph to 0.16 at 40 mph, similarly are used to determine minimum safe radii.

(c) Straight-ahead or braking friction factors for wet weather conditions ranging from 0.35 at thirty mph to 0.28 at seventy mph are used to determine safe stopping distances which establish minimum sight distances for provision throughout the highway.

(d) Speed-change rates used to establish length of deceleration lanes are equivalent to straight-ahead or braking friction factors ranging from 0.18 to 0.28 for deceleration from initial speeds of 30 to 70 mph, respectively.

Although the above friction factors are not referred to any particular form of test they necessarily represent values which correspond with those measured by braking a vehicle. They were determined as those to be nearly all-inclusive regarding variations in roadway types, vehicle and tire and weather conditions. Relatively uniform roadway surface characteristics necessarily are assumed. For other than completely adverse conditions the values used provide a substantial safety factor for the large majority of existing roadway surfaces. The critéria used in geometric design made no allowance for unsually low frictional values resulting from ice, bleeding asphalt, oil slicks, or very highly polished aggregates on the pavement surface. It is assumed that these are temporary conditions which will be eliminated by maintenance. Wet roadway surface friction factors used to determine design braking distances are logical check criteria for the determination of roadway surfaces that require corrective measures to provide essential highway safety.

10. One prolific source of skidding accidents is the presence of ruts in the shoulders immediately adjacent to pavement surfaces. Such ruts are extremely hazardous and should be guarded against with vigilance.

11. Preventive and corrective measures. Methods reported to have been used to improve the skid resistance of bituminous pavements with no other deficiencies include seal coats with non-polishing aggregate cover, resurfacing with siliceous rock asphalt, resurfacing with fine sand mixes designed to simulate rock asphalt, coating with epoxy resins with abrasive cover, and coating with asphalt-rubber latex covered with non-polishing aggregates. The use of thin silica sand mortar overlays for resurfacing resurfacing slippery concrete surfaces was also reported.

<u>Deficiencies in the Present Knowledge</u>: According to the report of the sub-committee D to the First International Skid Prevention Conference, University of Virginia, Charlottesville, Virginia, September 8-12, 1958 (20) the following are the deficiencies in our present knowledge.

1. Although some ingenious measuring devices have been built to

determine coefficient of friction, it seems to be desirable that these methods be carefully reviewed with the idea of insuring that all of the forces involved be fully accounted for. Devices of a given type should give practically identical results and until that can be assured, such devices cannot safely be used in a national standard. This does not at all imply that such devices are not valuable for comparing different road surfaces. They are extremely useful for rating road surfaces for slipperiness. A simple device for comparing the various methods used in different states is much to be desired.

2. Of immediate importance is the development of methods for proportioning and building road surfaces which will have built-in non-skid properties.

(a) Concrete pavement: In the concrete pavement, sometimes more sand is added in the mix with the idea of creating a thicker mortar surface than has been customary for many years. Air entrainment may possibly make this idea practicable. This is suggested as worthy of research. In the building of concrete pavement surfaces there is the possibility of vibrating anti-skid aggregate into the surface during construction. This has been done successfully in the laboratory. This has to be tried in actual construction. Also, when necessary, two-course construction can be resorted to, using a mortar top course.

(b) Asphaltic pavements: In the asphalt type of pavement proper proportioning and the use of anti-stripping agents to prevent flushing of the asphalt to the surface are desirable. Research along this line should be profitable.

Also, in the asphalt type, more work on the minimum percentage of siliceous sand needed to provide anti-skid properties is necessary. The proportioning of the mix which will result in the more rapid wear of the matrix than of the coarse aggregate may also sometimes beneficial. Possibly basic research on the asphaltic cement would be profitable.

3. The method of using a sand-asphalt, thin surface mixture as practiced in Virginia needs more wide spread investigation throughout the country in order to determine if this relatively lean surface mixture will be sufficiently durable under all conditions. If this type of mix is not found to be sufficiently durable, then further research on the durability phase of this type of mixture will be needed. Also, the contention by some that in heavy downpours, such fine textured surfaces may lose their skid resistance especially with regard to vehicles traveling at high speed, needs further investigation. The work of the NACA at Langley Field, showing the tendency of tires to"aquaplane" over heavy films of wster at high speed, is cited.

4. Other economical methods of improving the skid resistance of pavements having no other deficiency should be investigated both in the laboratory and on actual road surfaces.

5. Laboratory methods for studying pavement slipperiness and methods for overcoming it have been used with apparent success and

they offer great promise of furnishing valuable preliminary data prior to proof of these methods under actual road conditions. The calibration of laboratory devices in terms of permissible degrees of actual road slipperiness would be useful.

6. Pavements, like all other structures, need maintenance for their adequate preservation. Intense traffic has brought about the necessity for a new type of maintenances many more researches on the improvements of slippery road surfaces could be made with profit. The above are merely suggestions.

Accidents and Human element in Skidding

Skidding was reported as involved in four out of ten (41 per cent) rural accidents in Virginia in 1957, according to reports reviewed in a study covering 34,139 accident reports. In Great Britain in 1957, records indicated that one out of four (27 per cent) personal injury accidents on wet road surfaces involved skidding -- while on icy surfaces the proportion was four out of five (82 per cent). On the Pennsylvania Turnpike in 1952-1953, nearly one out of four accidents (22 per cent) involved failure of the driver to cope with road conditions. Most of these accidents involved skidding (11).

Not only is the general public uninformed, but there is evidence that all too many highway administraters and engineers, other officials, and even traffic and safety specialists are inadequately informed. Increasing development of free ways and other high-type highways, inevitably means higher speeds on such superior facilities. Further-more, traffic volume are increasing rapidly in many countries -- and at the same speed it is clearly more dangerous to skid when there are more vehicles on the road. Adequate and reliable accident data can be of great value in coping with skidding problems. Skid spot maps can identify bad skid zones. Such information can be used for safety of the public. Skid accident information can also be of practical use in highway design for reaching decisions as to sharpness of curves, intersection design, choice of road surfacing materials and so on.

The Human Element

While improvements affecting skidding will be produced through physical developments in roads and control devices, tires and vehicles driver actions will remain a dominant factor in skidding. Hence, it is highly important that interest in such physical development be paralleled by adequate attention to human factors.

From the analysis of driver-vehicle and highway factors in accidents and from other sources, it appears that many drivers are woefully uninformed about skidding. Matters often misunderstanding or unknown include the following according to the report of the sub-committee D to the First International Skid Prevention Conference, University of Virginia, Charlottesville, Virginia, September 12, 1958 (11).

1. Friction between tires and road is often greatly reduced when the road surface is wet, increasing vehicle stopping distances very greatly. The effect of wetness on slipperiness varies greatly with

different road surfaces, however.

2. Such friction for an emergency stop on most wet road surfaces is much lower in high speed stops. In a quite high-speed stop on a wet road, such friction is almost as low as that on ice.

3. Some road surfaces which are very non-skiddy when dry, become treacherously slippery when wet.

4. When a road surface is wet, its slipperiness cannot be judged easily by a motorist looking at it.

5. A shower after a dry spell on a heavily traveled highway may cause the highway, due to oil drippings and road film, to suddenly become very slippery until the rain cleans off the surface -- even on the best of road surfaces.

6. Even the slightest swerve, brake application or speed-up can "trigger" a skid on wet or icy road surfaces. The higher the speed, the more true this is.

7. Unevenly or badly worn tires may result in skidding and loss of control on wet roads the conditions of which are otherwise excellent.

8. Skidding is especially likely to occur at curves, near intersections, on steep hills, at traffic circles. One reason is greater pavement wear resulting in lowered friction coefficients. There are also places where drivers decelerate sharply, swerve or otherwise

change course rapidly.

9. Many drivers have not developed patterns for action in skids and understanding of what not to do. These are things which cannot be learned by reading alone; they must be experienced.

MEASUREMENT OF SKID RESISTANCE

General

In recent years there has been an increased awareness of the problem of slippery pavements. As a motor vehicle travels over a highway, the condition of maximum stability, during which the driver has complete control of the vehicles occurs when the wheels are rolling without slipping, i.e. when there is no relative motion between the tire and pavement. When the wheels are locked, which normally occurs during an emergency stop on a wet pavement, there is sliding without rolling, and the driver retains very little steering control.

A difference of opinion as to which of the above conditions is the most significant with regard to evaluating the skid resistance of a pavement surface is one reason for the wide variety of skid rest equipment developed over the past thirty five years. In Europe, the view point is that "cornering" represents the critical condition and the emphasis has been on measuring the sideways skid resistance. In the United States, however, the majority of the field testing programs have evaluated the skid resistance of surfaces by a straight ahead skid along the length of pavement. Most of the field testing in this country has stemmed from the work of Agg and Moyer at Iowa State College. One of the conclusions from their original series of tests, which included both sideways and straight-ahead skid test measurements, was that the straight ahead method gave results which evaluated the surfaces on the same relative basis as the sideways method and required somewhat less complicated instrumentation. Subsequent skid test studies by Moyer, as well as the other major slipperiness investigations performed in this country, have consisted of straight-ahead skid determinations (25).

Field Tests

1. Passenger-car Braking Tests: The most common type of field skid test is one in which the wheels of a test vehicle are locked at a given speed and the behavior of the sliding vehicle is observed. Tests of this nature have been performed in conjunction with research in tire design, in accident investigation, and in evaluation studies of the anti-skid properties of different types of pavement surfaces.

a. Stopping-distance test: From reference (25) the forces developed in braking a passenger car with all four wheels locked constitute a relatively simple force system, as illustrated in figure 5. The total weight of the test vehicle (w) is shown as acting through the center of gravity and is reacted by the normal forces at the front and rear wheels (N_1 and N_2). The horizontal force tending to decelerate the vehicle is composed of the frictional forces generated at the front and rear wheels (F_1 and F_2) because of couple with the decelerating force, resulting in a load transfer to the front axle and an increase in N_1. If it is assumed, however, that an average coefficient of friction exists for the front and rear wheels, the following relationships hold:

$$F_{vertical} = 0$$

$$W = N_1 + N_2$$

$$F_{horizongal} = Ma_{horizontal}$$

$$F_1 + F_2 = \frac{W}{g} \times a \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_(1)}$$

From friction concepts

$$F_1 = \tan Q\ N_1 = f\ N_1$$

$$F_2 = \tan Q\ N_2 = f\ N_2$$

where Q = friction angle

f = coefficient of friction

$$F_1 + F_2 = fN_1 + fN_2 = f\ (N_1 + N_2) = f\ W$$

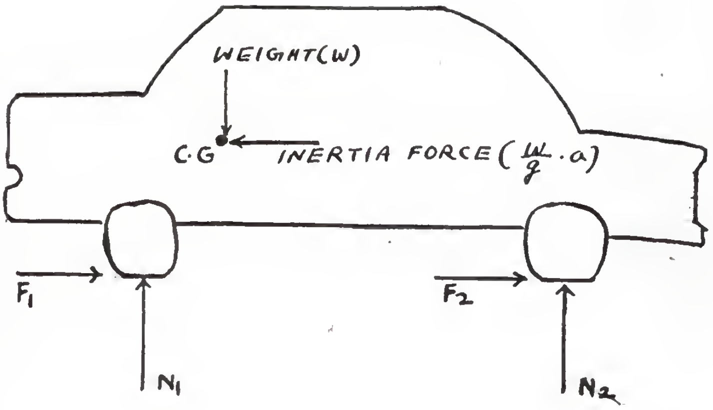
Substituting in (1)

$$f\ W = \frac{W}{g} \times a$$

$$f = a/g \text{ or } a = fg$$

where a = average rate of deceleration

g = acceleration due to gravity



FORCES DEVELOPED IN BRAKING A PASSANGER CAR

EXTRACT FROM "PAVEMENT SLIPPERINESS", HIGHWAY ENGINEERING HAND BOOK, WOODS. SECTION 20, P.P 20-1-20-27, 1960.

FIGURE 5

By substituting this average value for rate of deceleration in the basic mechanics formula, the following equation results.

$$S = \frac{V^2}{30\ f}$$

where S = total stopping distance in feet required to skid to a stop if brakes are applied at initial speed of V mph,

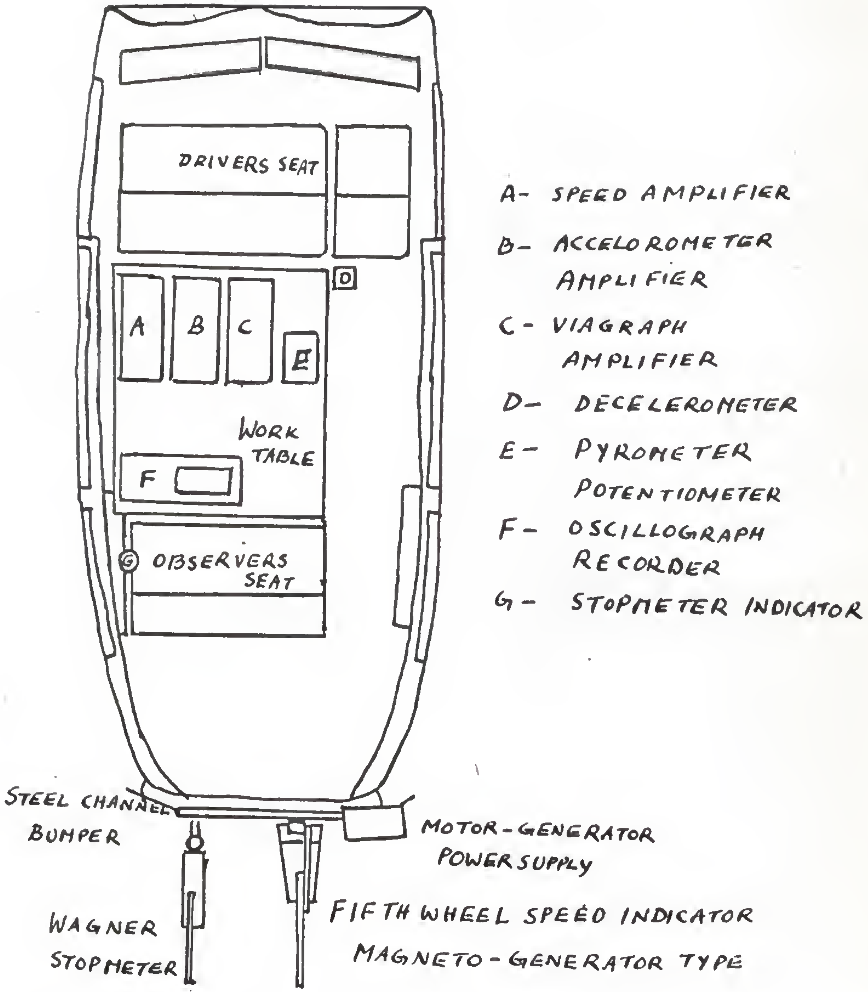
and f = average coefficient of friction between four tires and surface over entire speed range from V mph down to zero mph.

In the majority of the braking test studies the total stopping distance is determined. Moyer and Shupe (7) performed braking tests at speeds from ten to forty mph except on certain slippery wet surfaces where it was found to be too dangerous to attempt a braking test with a passenger car from forty mph. A general layout of the equipment used in the passenger car stopping distance tests is shown in figure 6. In this test the braking distance is measured with the Wagner fifth wheel stopmeter. The stopmeter is tied in with the stoplight circuit so that the instant the brakes are applied the braking distance is measured by means of the fifth wheel, and after the car stops, the observer in the car reads the stopping distance on the stopmeter indicator dial.

Nichols Jr; Dillard and Alwood (17) conducted the braking test studies by the same stopping distance method reported by Shelburne and Sheppe in 1947, except that the test has since been streamlined for speed. Pavements are no longer tested in a dry condition; also, testing at very low speeds has been discounted. Only good tread tires are used.

b. Rate of deceleration test: British Road Research Laboratory evolved a test procedure for a commercially available portable decelerometer, which is simple, reliable, requires no maintenance, and can be purchased in the United States for under $200. This meter is of the damped pendulum type which has a scale reading directly in g's. If the wheels of the vehicle are locked an air friction is neglected, the meter then reads the coefficient of friction directly. The meter, mounted on a heavy base, is set on the floor of the vehicle. The vehicle is brought to a speed of thirty mph on the site to be tested, and the brakes applied with sufficient force to lock the wheels. At the end of one second, the brakes are released, and the decelerometer reading recorded. A ratchet device causes the meter to record the maximum deceleration reading obtained during one second interval. The British have obtained very good empirical correlations between friction measurements obtained in this manner and measurements obtained by other means (1).

Moyer and Shupe (15) used a Statham linear decelerometer for the measurement of the instantaneous deceleration rate at various speeds in the locked -- wheel stopping tests. The Statham decelerometer is a sensitive transducer or pick up device which measures linear acceleration or deceleration from zero to two g. The acceleration or



SCHEMATIC DRAWING OF CARRALL USED FOR PASSANGER CARSKID TESTS

EXTRACT FROM "ROUGHNESS AND SKID RESISTANCE MEASUREMENTS OF PAVEMENTS IN CALIFORNIA", HIGHWAY RESEARCH BOARD BULLETIN 37 P.P 1-37 (1951)

FIGURE 6

deceleration is recorded by the use of a special amplifier and a brush direct recording oscillograph. An accurate oscillograph record of speed during the test is obtained by the use of a fifth wheel, speed amplifier and the brush oscillograph record of speed during the test is obtained by the use of a fifth wheel, speed amplifier and the brush oscillograph. This method requires complex instrumentation with a corresponding increase in initial cost of equipment, but does give an excellent indication of the skid resistance of pavement surfaces over a wide speed range.

c. Towed-vehicle skid tests: Towed-vehicle tests have been used quite extensively, both in this country and in Europe, primarily to evaluate the skid resistance of different surface types, and also in tire design studies. In tests of this nature a vehicle is towed at a constant speed, with the pulling force being measured by a dynamometer. The force required to tow the vehicle before and after the wheels are locked is determined, with the difference between these two values representing the braking effort developed between the tires and the roadway. Dividing the braking effort by the normal force between the tires and the surface results in the coefficient of friction (25). Moyer and Shupe (15) used a two wheel trailer equipped with electric brakes. For the general run of the tests the trailer was loaded to provide a typical passenger car axle load of 1820 lb. The tow truck was an FWD truck with a rating of 172 H.P. at 2600 RPM. The truck had ample reserve power so that it could be operated at various uniform speeds upto fifty mph with the brake on one trailer wheel locked. The trailer was constructed along conventional lines with certain special provisions required to run locked wheel and the variable force braking tests. The trailer was equipped with a soft suspension system consisting of long leaf springs, coil springs and hydraulic shock absorbers designed to keep the trailer body as free as possible from vibrations caused by road roughness. By increasing the load on the truck body and by installing shock absorbers on both the truck and trailer, the vibrations were greatly reduced and as a result of these changes satisfactory oscillograms are now obtained. The trial wheels were free rolling when the brakes were released. The maximum braking force at each speed was measured with an SR-4 strain gap dynamometer, of the proving ring type. In the calibration of the dynamometer, it was found that the braking forces can be measured to an accuracy of $\pm$ 2 per cent for forces upto 2,000 lb. The dynamometer was attached to the tow truck and trailer directly in line with the longitudinal axis of the wheel being braked. It was fitted with universal joints and a short length of chain to eliminate torsion or any other restraint not directly induced by the braking force. The tongue of the trailer was suspended on a cradle in such a way that only vertical forces could be transmitted by it to the truck.

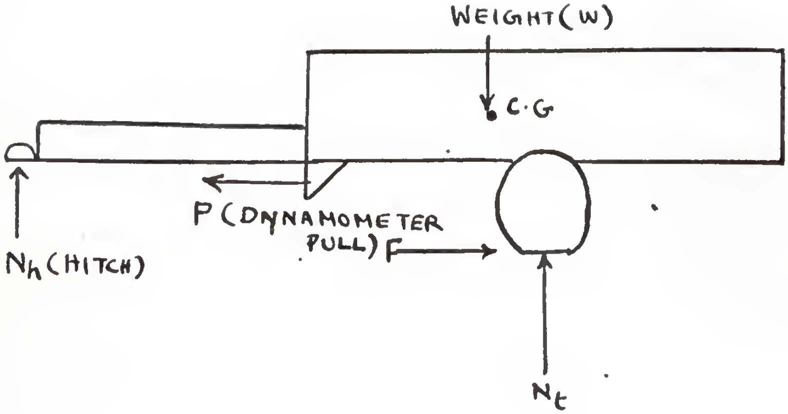
Figure 7 illustrates the forces developed in braking a two-wheel trailer of the type developed at the University of California (15) as described above. The weight is shown acting through the center of gravity and is reacted by the normal force between the tires and surfaces (N_t) and by the vertical force at the hitch (N_h). When a trailer wheel is braked, the couple formed by the frictional force between the surface and the F and the dynamometer pull P causes a load transfer, increasing the load on the hitch and decreasing the total contact pressure between the tire and surface. This load transfer can easily be computed using the geometry of the trailer so that the coefficient of friction is expressed by the following equation.

$$f = \frac{F}{N_t}$$

where f = braking effort, lb. i.e. difference in pulling force before and after wheel is locked

and N_t = normal force, lb. between tire and surface, with adjustment included for load transfer.

A two-wheel towed trailer unit has also been developed by Skeels of the General Motors Proving Ground (30). A car was equipped with instruments for measuring the reaction of the rear wheel brakes; the front wheel brakes were disconnected and the car towed behind a sprinkler truck. The rear wheel brake reaction was read on a servo type of direct reading indicator calibrated to read pounds of force at the road surface. This equipment was similar in many respects to the California apparatus, but was somewhat simpler and therefore less expensive. The trailer was constructed from a post-war buick chassis. This model of vehicle was specified since it used a torque tube drive



FORCES DEVELOPED IN BRAKING A TWO-WHEEL TRAILER

EXTRACT FROM "PAVEMENT SLIPPERINESS", HIGHWAY ENGINEERING HAND BOOK, WOODS SECTION 20, P.P 20-1 - 20-27, 1960

FIGURE 7

with coil springs which lends itself well to the installation of strain gauges for measuring brake reaction. A pick up truck towed the trailer and carried two fifty gallon drums for wetting a strip of pavement by gravity flow directly in front of each tire. Both wheels were locked during testing, resulting in an average coefficient of friction for the two wheel paths. This equipment, also, was adaptable to evaluate the impending or incipient coefficient of friction.

d. Advantages and disadvantages of the three methods: 1. The passenger car stopping distance and rate of decelration methods have the following advantages.

i. The locked wheel braking tests closely simulate actual vehicle operation and provide an accurate measure of the road and tire friction developed by a passenger car when making an emergency stop for similar road and tire conditions.

ii. The initial cost of equipping a vehicle for performing locked-wheel tests is relatively cheap as compared with other methods of evaluating pavement slipperiness.

iii. In simulating actual roadway performance, this procedure generates greater confidence in its results than some of the more indirect methods of determining skid resistance, particularly with laymen, non-technical administrators, and juries.

Disadvantages: i. The tests require the use of special traffic control measures such as flagman and warning sighs.

ii. The tests are hazardous at speeds above thirty mph, especially on slippery wet surfaces.

iii. The tests do not give an accurate indication of the anti-skid characteristics of pavements at the speeds at which traffic normally flows on rural highways.

iv. For wet testing auxiliary spraying equipment is required.

v. This type of braking test is dependent upon the period of response of the various braking and measuring components, and results are not always reproducible for similar testing units.

2. The truck trailer method used in California and by the General Motor units has the following advantages.

i. The anti-skid properties of pavement surfaces are determined for speeds at which traffic normally operates.

ii. Tests are run with a minimum of interference to traffic, and no traffic control is necessary.

iii. There is no hazard to operating personnel with regard to losing control of the vehicle.

iv. The wet tests are easy to make, do not require an auxiliary water truck, use less than 1/10th the amount of water used when sprinkling road with truck, and do not create a skidding hazard to other traffic on the road.

v. The tests can easily be standardized as to load, tire types, tire size, and the general test procedures.

Disadvantages: The equipment used in the tests is highly specialized and the investment cost is quite high.

e. Comparison of results obtained by three different methods of testing skid resistance in California.

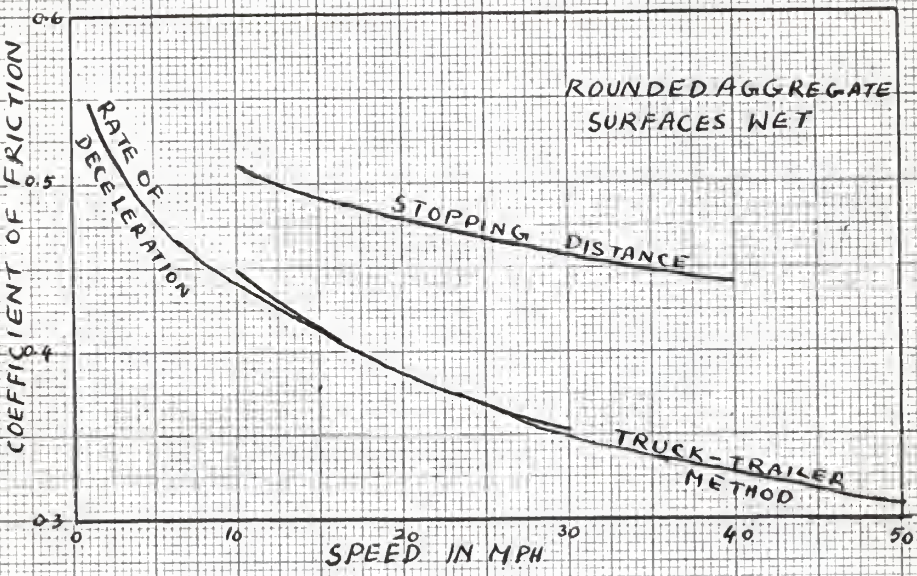
Moyer and Shupe (15) performed experiments and compared the results obtained by different methods of testing skid resistance. This is plotted in figures 8 and 9. It is seen that the friction values as measured using the truck trailer and the rate of deceleration methods were very nearly the same at corresponding speeds, whereas the values based on the stopping distance method and when plotted in terms of the initial speed, were about twenty five per cent higher than the values obtained by the other two methods. The higher values obtained using the stopping distance method may be explained in part by the fact that the friction values are average values over the entire stopping distance and thus they can be considered as the friction values for the average speed instead of initial speed. However, even if this change is made the friction values by the stopping distance method will still be higher than the values by the other two methods. An additional reason for the higher values is that the stopping distance method combines the effect of impending-skid and sliding-wheel braking forces while only the sliding wheel braking forces are measured in the other two methods. Since the impending-skid braking forces are 25 to 100 per cent greater than the sliding wheel braking forces, the higher friction values as reported for the stopping distance method in figures 8 and 9 are fully accounted for (15).

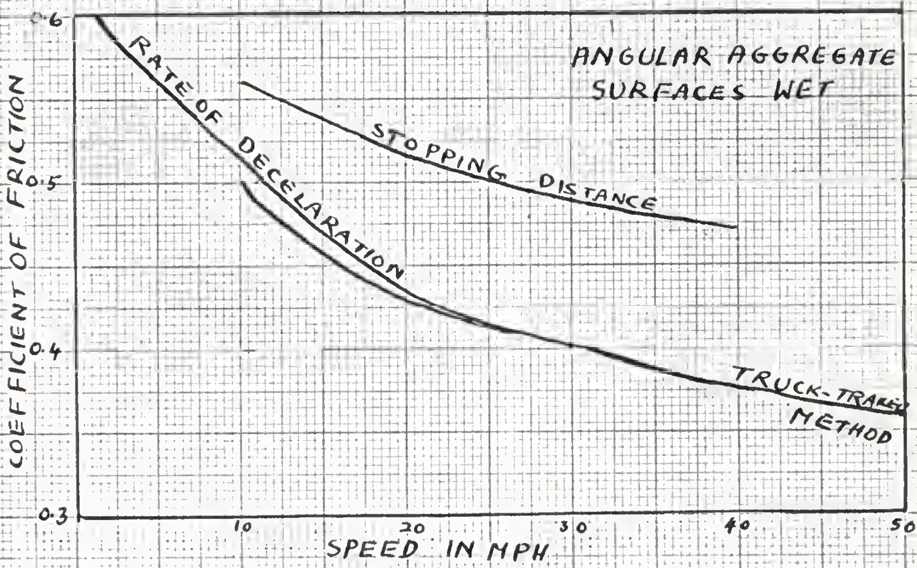
f. Comparison of several methods of measuring road surface friction: In the United States of America several machines are used for measuring the road surface slipperiness. The existing methods differ appreciably in their designs and the results they obtain. These differences make difficult the pooling of data collected by various agencies throughout the country and in general hamper progress toward safe, anti-skid roads. Dillard and Allen (5) conducted experiments and gave the following conclusions.

1. The coefficients of pavement friction obtained by the different machines included in the study differed substantially, both statistically and from a practical stand point. Qualitative differences in results made it impossible to make measurements of the different machines comparable to one another by the use of an additive factor.

2. The relationship between measurements made by trailer and measurements made by the stopping distance method were not clarified. Some trailer results were higher than expected, some lower, with respect to the stopping distance results. Further research is needed on this problem.

COMPARISON OF RESULTS OBTAINED BY DIFFERENT METHODS OF TESTING SKID RESISTANCE OF OPEN GRADED ASPHALT SURFACES



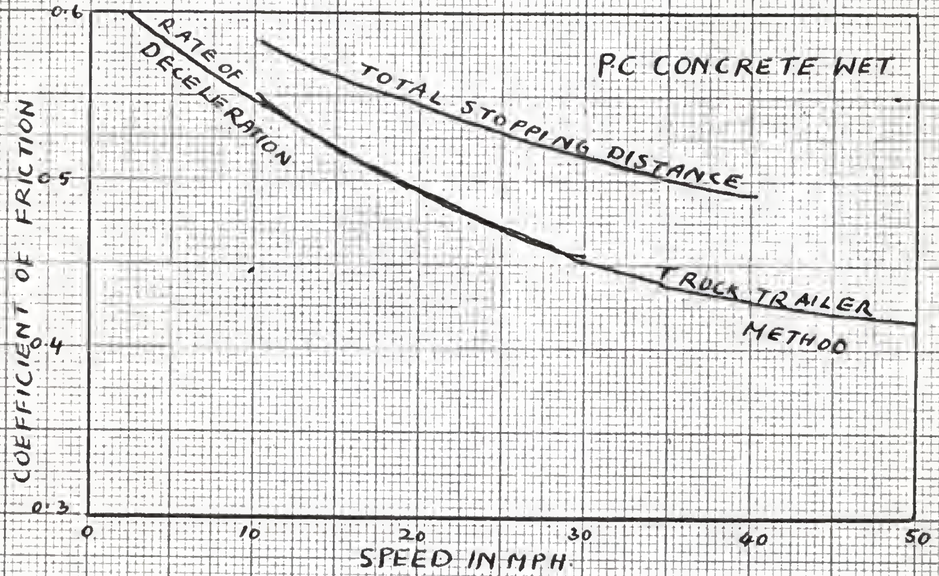


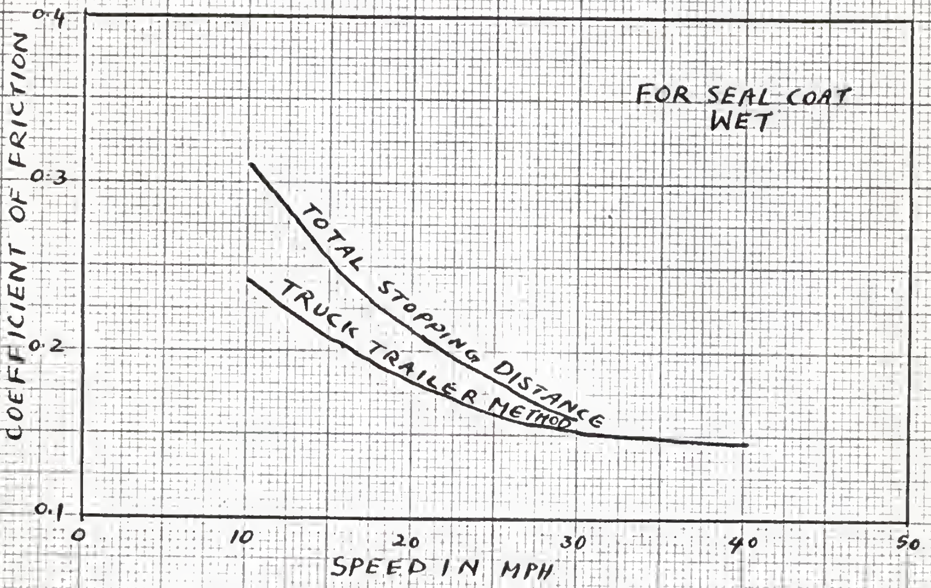
EXTRACT FROM "ROUGHNESS AND SKID RESISTANCE MEASUREMENTS OF PAVEMENTS IN CALIFORNIA", HIGHWAY RESEARCH BOARD BULLETIN 37 P.P 1-37 (1951)

FIGURE 8

282

COMPARISON OF RESULTS OBTAINED BY DIFFERENT METHODS OF TESTING SKID RESISTANCE





EXTRACT FROM "ROUGHNESS AND SKID RESISTANCE MEASUREMENTS OF PAVEMENTS IN CALIFORNIA", HIGHWAY RESEARCH BOARD BULLETIN 37 P. P1-37 (1951).

FIGURE 9

ares to the Inch

3. The locked-wheel coefficients obtained with different types of tires indicate that results from different tires can be correlated by an additive factor. Although this factor will differ from tire to tire, it appears to hold across the various levels of friction.

4. There were important differences between machines in terms of the variability of successive measurements of the same pavement. The data suggest that variability is related to design characteristics of the machines.

5. The variability of measurements was not influenced by level of friction. This indicates that the precision of measurement of coefficient of friction is about the same for high-friction pavements as for low-friction pavements.

g. Selection of a skid test method for a field investigation.

The selection of an appropriate method of testing will depend upon the nature and the extent of the contemplated program.

For a limited accident investigation or an urban-area study in which vehicle speeds are relatively low, the passenger-car stopping distance method would be entirely adequate. If a limited study is to take place on rural highways or in urban areas where high vehicular speeds are anticipated, it would be well to consider the use of a decelerometer, since the stopping-distance method may not always be an accurate measure of skid-resistant properties at high speeds. The truck trailer method is best suited of the three methods to an extensive field investigation of pavement slipperiness.

C. Laboratory Tests

1. Purdue University skid-test apparatus: The laboratory test procedure was developed to evaluate the skid resistance of portland cement or bituminous specimens molded in the laboratory or cored from the pavement surface (28). The laboratory skid test apparatus spins a six inch diameter test specimen at a constant speed of 2500 rpm and measures the skid resistance by forcing a rubber testing shoe against the surface of the test specimen with a unit pressure of 28 psi. The amount of torque developed in the shaft supporting the testing shoe, due to the skidding action of the shoe on the test specimen, is automatically recorded as a measure of the wet skid resistance of the specimen. A complete discussion of the laboratory skid test apparatus is seen in reference (26).

A field correlation study was performed on thirty different portland cement and bituminous pavements representing a wide variety of surface types and textures. Three wet stopping-distance tests were run on each of the test specimens, after which three cores were taken from the test area and evaluated in the laboratory skid-test apparatus. In general, there was good agreement between the two methods of evaluating pavement slipperiness (25).

2. University of Kentucky investigation: A basic study of the polishing characteristics of limestone and sand stone in regard to pavement slipperiness was made at the University of Kentucky (32).

Four inch diameter stone cores were used as the test specimens in this investigation and were ground down to their most slippery condition with eighty 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 (25).

3. Universit͟y͟ o͟f͟ T͟e͟n͟n͟e͟s͟s͟e͟e͟ e͟q͟u͟i͟p͟m͟e͟n͟t͟: A procedure has been developed for evaluating the potential slipperiness of paving mixtures at the University of Tennessee (12). 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 ten mph and a total load of 270 lbs. The equipment is also used in wearing and polishing a test specimen (1).

4. National Crushed Stone Association Procedure: NCSA has been active in investigating the anti-skid characteristics of different types of paving mixtures (21,22). The slipperiness is evaluated by lowering a rotating bicycle tire on 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 fifteen feet diameter test truck, eighteen inch 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 (25).

EFFECTS OF AGGREGATE FACTORS ON PAVEMENT FRICTION

Stephens and Geotz performed tests on aggregates and arrived at the following conclusions (31). Tests performed on surfaces of controlled-shape aggregate particles gave general indications of the relationship between the effect of particle edges and particle surfaces. The contribution of the edges to the relative resistance values of larger, smooth aggregate particles was a small increase in resistance. The creation of edges in boldly textured aggregate reduced the relative resistance value.

Area of aggregate exposed in the surface of the specimen and thus available to the rubber shoe for friction had a major effect on the relative resistance value. The greater the ratio of aggregate exposed to the total surface area, the greater the relative resistance value. The rate of this trend was strongest for low ratios, moderated as the area of aggregate approached one-half of the test surfaces, and remained nearly constant thereafter.

Several specimens tested under various pressures showed increases in relative resistance value with increased contact pressure. For coarse aggregate pavement, the rate of increase was dependant on material rather than on aggregate shape. This rate was greater for strongly-textured stone such as sand stone than for soft material such as limestone.

The use of different abrasives for polishing rock cores prior to relative resistance value tests indicated that the degree of polish attained for a given effort is a function of both the rock from which the core was cut and the abrasive used. The use of an abrasive which was harder than the cores, caused a continual reduction in relative resistance value as the size of abrasive was reduced. The use of abrasive identical with the cores established that for each material there was a definite size of similar abrasive which gave the surface a polish resulting in the highest relative resistance value. For the limestones used in this study the abrasive size which resulted in the highest relative resistance value was that passing a no.100 sieve and retained on a no.200 sieve.

Bituminous mixtures using crushed and round silica sand were used to establish the size of granular surface texture which resulted in the highest relative resistance value. For crushed silica this size was 0.0175 inch in diameter. For round silica, a size below 0.0088 inch was indicated.

POLISHING CHARACTERISTICS OF MINERAL AGGREGATES IN REGARD TO PAVEMENT SLIPPERINESS

General

The anti-skid properties of a well designed pavement surface are dependant 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 dependant 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.

For the past few years, Kentucky has required fifty per cent natural silica sand in high-type bituminous concrete surface courses (32). This is in response to a desire to "build in" skid resistance and recognizes the susceptibility of surfaces composed entirely of limestone aggregates to polish and become slick. The work in Virginia has demonstrated that twenty five to thirty per cent sand gives slight although inadequate improvement in skid-resistance (33), and the work in Tennessee has indicated further improvement as the percentage of sand is increased.

Since test data from various sources prove rather conclusively that limestone surface courses are inherently responsible for slickness, this doesnot present a very favorable outlook for a state where limestones are abundantly used for highway construction, unless skid-resistance can be artificially induced in the limestone or also achieved by some other means. 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.

Limestone

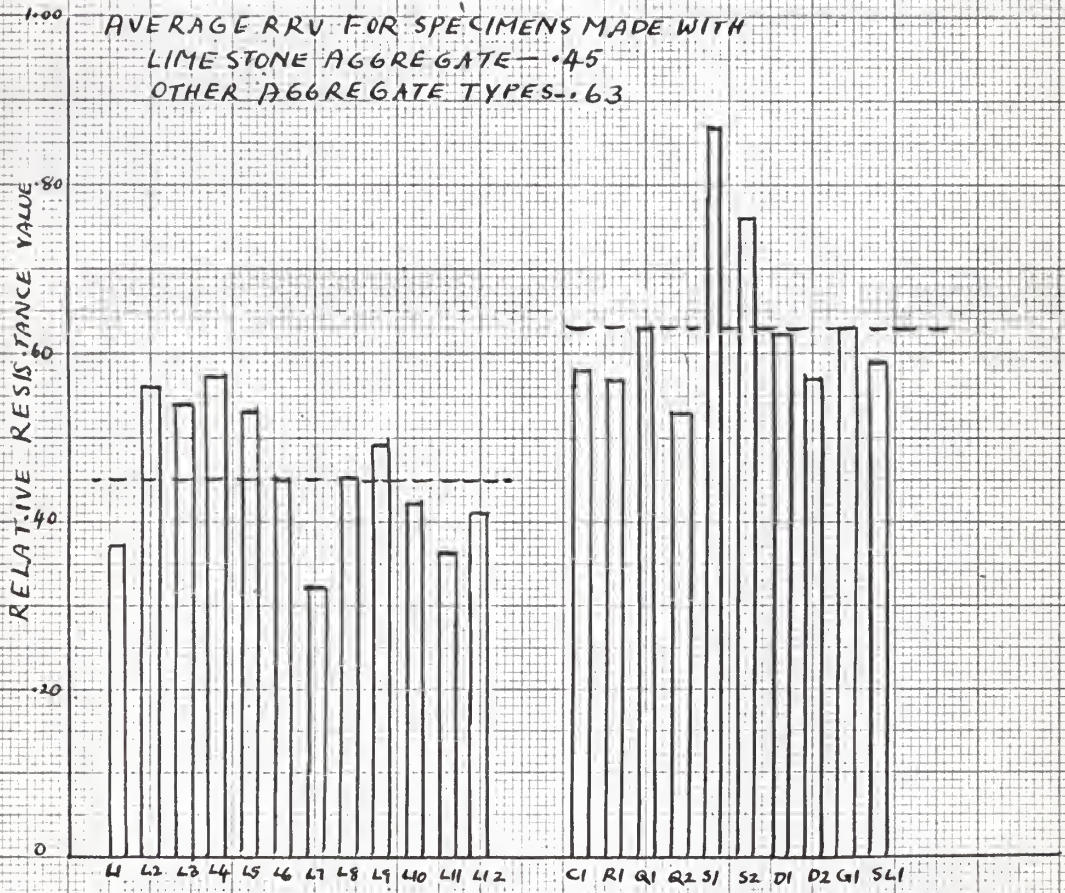
Limestones, as a group, have developed a poor reputation with regard to susceptibility to polishing. Studies in Virginia (17), Tennessee (33) and Kentucky (32) have indicated that both bituminous and portland cement surfaces, in which the aggregate consists entirely of limestone, may become slippery under the action of traffic, and measures have been taken to limit the use of limestone, asa surface material in these three states. Stutzenberger and Havens made the following conclusions after their tests regarding limestone (32).

Limestones rank third in the hardness scale and are therefore susceptible to polishing or wear by almost any grit that might be present in road scum. However, some differences among limestones are apparent; and these seem inherently related to the size, interlocking and cementation of the crystals. Fine grained, dense stone polished more readily than coarse grained stone gave consistantly lower wet friction coefficients and higher gross readings. Close attention to the photomicrographs of the polished and roughened surfaces and thin section of these stones will show the variations in grain size and crystallization. None of the limestones showed any evidence of grains being torn out of their sockets during polishing.

The results of a laboratory investigation at Purdue University (29) in which the resistance to polishing of twenty two mineral aggregates from five different states were studied, are summarized in figure 10. The results for test specimens made with twelve limestones included in this study which are identified as L-1 to L-12 are plotted to the left in figure 10, with values for mixtures containing the other ten aggregates listed to the right. The twelve limestone specimens, with an average RRV of 0.45 possessed less resistance to polishing, as a group, than mixtures containing the other ten aggregates, which averaged 0.63. There was also appreciable variability in the polishing characteristics of the different limestones, with specimens containing L-4 exhibiting seventy per cent greater skid resistance than those made with L-7.

Petrographic and chemical analyses were performed on the twelve limestones used in the study. Those limestones which readily polished possessed either a very fine-grained crystalline structure or consisted of rounded oolitic grains supported in a calcite matrix of similar hardness. For both cases, however, the limestones were almost pure calcium carbonate, and the nature of the wear was very uniform, resulting in a highly polished surface that was slippery when wet.

The limestones which exhibited the best anti-skid characteristics



RESISTANCE TO POLISHING OF BITUMINOUS MIXTURES COMPOSED OF DIFFERENT AGGREGATE TYPES

EXTRACT FROM "POLISHING CHARACTERISTICS OF MINERAL AGGREGATES" PROC, FIRST INTERNATIONAL SKID PREVENTION CONFERENCE UNIVERSITY OF VIRGINIA CHARLOTTESVILLE, 1958.

FIGURE 10.

were crystalline granular limestones composed of angular interlocking grains. For the twelve limestones under consideration, this structure occured with those limestones relatively low in calcium carbonate and high in "impurities", which consisted primarily of magnesium carbonate with a slight amount of silica. Consequently, for this investigation the highly dolomitic limestones exhibited the best resistance to polishing.

Sand Stones

Sandstones when used as a conventional aggregate in paving mixtures are skid resistant (33); and laboratory investigations at both Kentucky (32) and Purdue (29) have established the high resistance of sand stone to polishing. Referring to figure 10, the two aggregates identified as S-1 and S-2 which show appreciably greater skid resistance than the next best aggregate, were both sandstones.

In general, sandstones are composed of small angular quartz grains supported by a somewhat weaker cementing matrix. This combination results in excellent antiskid characteristics. The individual quartz grains are highly resistant to polishing, since quartz is no.7 on Moh's relative hardness scale, and the only material present on the highway capable of polishing it is more quartz. Calcite, one of the major constituents of limestone, is no.3 in the hardness scale. In addition, there is a particle-by-particle type of wear, so that before an exposed quartz grain has the opportunity to become highly polished, it is dislodged from the weak cementing matrix and a fresh, harsh particle appears at the surface (25).

Other Aggregate Types

All aggregate types other than limestone and sandstone are grouped under this category. Some of the fine-grained uniform aggregates passes polishing characteristics similar to those of the more resistant of the limestones. This is observed in figure 10 by the results for the chert (C-1) and rhyolite (R-1) aggregates. Initially, bituminous mixtures containing these two harsh aggregates exhibited high resistance to skidding, but during the simulated wear and polish procedure the uniform nature of wear lowered the skid resistance to values comparable with those of specimens containing highly dolomitic limestone. Another factor contributing to the decrease in skid resistance of bituminous mixtures composed of these two aggregates was the particle orientation that occurred during the rolling cycle (25).

Aggregate polishing is generally treated as a function of the traffic. Some gravels, however, are highly polished in their natural state and, if used in an uncrusted condition, may constitute an extreme skidding hazard. A seal coat constructed in California with polished beach gravel exhibited very little resistance to skidding when wet (20). Both the accident records and the coefficient-of-friction values, which were less than 0.2 at fifty mph, identified as slippery when wet (25). This condition is shown to a certain degree in figure 10. Aggregates Q-1 and Q-2 were both high quartz gravels. All the aggregate used in the Q-1 test specimens was crushed, but for Q-2 specimens the coarse aggregate fraction consisted of the natural rounded gravel. The Q-1 specimens exhibited over twenty per cent greater resistance to skidding than the Q-2 specimens. In figure 10 (D-1 and D-2) refer two diabases, (G-1) a granite and (SL-1) a blast furnace slag. These aggregates all imparted adequate skid resistance to their respective bituminous mixtures with the relative resistance values falling slightly above those of the best limestones but appreciably below those of the sandstones.

MINIMIZING PAVEMENT SLIPPERINESS IN NEW CONSTRUCTIONS

General

The mounting number of highway deaths, the rapidly growing property losses due in many cases to skidding accidents, and the increasing concentration of vehicles on the highways testify the need for a skid-resistant roadway surface in many critical areas. Currently, however, and with increasing importance as the polishing effect of traffic becomes more intensified, it is essential for the highway engineer to consider the anti-skid properties of a paving mixture in addition to the other design parameters.

Portland Cement Concrete

Portland cement pavements have not exhibited extremes in skid resistance that have been noted with bituminous surfaces. In Portland cement concrete, the individual pieces of aggregate are supported by the mortar and are not exposed to traffic to as great as a degree as with some types of bituminous surfaces.

1. Finishing procedure: The initial skid resistance of a portland cement pavement will be dependent upon the nature of the finish that the surface receives and the type of fine aggregate in the mortar. A well designed concrete mix with good workability and with minimum of segregation should result in a pavement with high initial skid resistance. If an excess of finishing is required, however, the surface may consist essentially of cement paste which exhibits poor anti-skid properties.

The final texture may be supplied to the pavement with a burlap drag or a longitudinal or transverse broom drag. By any of these methods it is possible to get coarse sandy texture possessing good skid resistance. It is not necessary to broom deep grooves in the pavement. It is necessary however, to use a delay-finish procedure, for if the drag is applied while the mortar is too soft, a dense smeary surface is obtained rather than the desired coarse sandy texture (14).

2. Concrete aggregates: For a properly finished portland cement surface the initial skid resistance will depend upon the angularity and hardness of the fine aggregate contained in the mortar. A harsh resistant sand will result in somewhat greater skid resistance than either a rounded natural sand or a crushed softer aggregate. As traffic begins to polish the surface, it is imperative that some type of differential wear of the various components occur. If the cement

paste and the fine aggregate both possess essentially the same resistance to wear, a uniformly polished surface may result that is slippery when wet. If the concrete also contains a coarse aggregate with similar wear characteristics, the uniformity of polish increases as wear progresses. The major occurrence of slipperiness for portland-cement-concrete pavements has been with mixes consisting entirely of crushed limestone fine and coarse aggregate. Consequently, if at all possible, a fine aggregate, such as natural sand, with wear characteristics dissimilar to those of the cement paste should be used in concrete mixes, particularly if the coarse aggregate is limestone (25).

In recent field studies in Indiana (13,27) in which over sixty concrete pavements were tested for skid resistance, not a single surface was found to be dangerously slippery when wet. Some of these sections were over thirty years old and showed considerable wear. However, all the mixes had been made with natural sand fine aggregate, and the differential nature of the wear had prevented the surfaces from polishing excessively. A number of concrete pavements have been constructed in Indiana containing 100 per cent limestone, but it was impossible to test these sections since, without exception, they have been resurfaced because of their slippery condition. High quality fine aggregate should present in concrete, particularly if a coarse aggregate with low wear resistance is present in the mix. If the concrete contains a wear resistant coarse aggregate which will ultimately project above the mortar datum, then this aggregate should be crushed. A naturally rounded pebble will polish more readily and to a higher degree when exposed to the action of traffic than will a harsh angular piece of aggregate (25).

Bituminous Surfaces

The following points have to be considered while constructing skid resistant bituminous surfaces.

1. Eliminate polished aggregate, which may arise at this polished conditions either naturally or because of the action of traffic, from the pavement surface.

2. Prevent an excess of asphalt from accumulating at the surface.

Asphaltic Concrete: In asphaltic concrete reasonable quantity of asphalt should be used for better anti-skid properties. A related problem pertains to the degree of openness of the asphalt concrete. Some engineers advocate an open-graded mixture containing coarse aggregate in which the large surface voids facilitate draingge from between the sliding tire and surface and promote better skid resistance. To a certain extent this is true, practically for a smooth-tread tire. However, the degree of harshness and the shape of the individual magnitude pieces of aggregate are more important than the openness of the surface in eliminating the water film, and there is evidence to the effect that greater skid resistance can be developed by loading the tire uniformly over its entire area, rather than by having voids of appreciable individual magnitude in the surface. The sand-asphalt type of pavement of the coastal plain area of Virginia is an example of a non-skid surface in which the individual voids are small (24).

Laboratory studies at Purdue (29) also indicate that if there is no excess of asphalt present, dense graded mixtures exhibit better resistance to skidding than open-graded mixtures. Therefore, although open-graded mixtures possess a higher void content than dense graded mixtures. Currently, there is some disagreement as to whether an open- or dense-graded asphaltic concrete does possess the better anti-skid properties. However, as improved design and control procedures tend to eliminate the possibility of a bleeding asphalt surface, dense graded mixtures will probably emerge as the more skid-resistant of the two (25). Field studies in Virginia (6) and laboratory work at Purdue (33) indicate that very sizable quantities of of a resistant silica sand are required to appreciably increase the skid resistance of a bituminous mixture composed of a polish-susceptible coarse aggregate.

2. Bituminous surface treatments: In these constructions care should be taken to use required quantity of bitumen without any excess and also slecting suitable aggregate against polishing action of the traffic.

IMPROVING THE ANTI-SKID PROPERTIES OF SLIPPERY PAVEMENTS

Deslicking existing Surfaces

A number of methods for improving the skid resistance of slippery pavements by modifying the existing surface have been developed over the past twenty years. These methods are not popularly used because that they do not correct the initial cause of pavement slipperiness, and although temporary improvement in skid resistance is frequently realized, the surface will generally return to a slippery condition after a relatively short period of wear.

1. Portland Cement Concrete: One of the early methods of deslicking polished portland cement concrete involved in the direct application on the pavement surface of a dilute hydrochloric acid (7). The acid reacts with the cement paste as well as with any calcareous surface aggregate, and etches the smooth surface so that the resulting texture shows an increase in skid resistance over the polished surface. Another method is mechanically roughen the surface. The surface may be sand blasted, chipped, or ground with rotary drills, with as much as 1/16 inch of the concrete being removed (8,9). A related procedure is the Kogel process, in which the surface is heated by different flames on to the pavement from a hand-propelled generator (10). The high temperature attained causes the surface to spall, resulting in a roughened texture similar to that achieved by mechanical process (25).

2. Bituminous Surf ces: Deslicking procedures for bituminous surfaces generally involve the elimination of slippery sections of bleeding asphalt pavements. One of the common methods of "blotting" an excess of asphalt at the surface is to spread a surplus of sand over the bleeding area and permit traffic to roll the sand into the asphalt. This may provide temporary improvement in skid resistance, but generally the degree of aggregate retention is small, so that the asphalt may drown the retained aggregate and again present a flushed surface after a short period of wear. A related procedure was developed in Texas in which crushed stone was treated with kerosene, placed on the slippery areas, and rolled into the surface (3). The kerosene reduced the softening point of the asphalt and promoted retention of the crushed stone. A treatment developed in California for roughening slick seal coats involves softening the binder by means of heat and grooving the surface with a rake type drag (2). This results in an improvement in skid resistance, but leaves an unsightly riding surface and one which gives the driver a feeling of pavement instability. The longitudinal grooves tend to guide the vehicle, so that the operator does not retain complete steering control (25).

Non-skid Surface Treatments

Non-skid surface treatments are composed mainly of fine grained abrasive materials and are somewhat more expensive than the conventional bituminous surface treatment. However, they do possess excellent anti-skid characteristics, both initially and after appreciable amounts of wear.

1. Kentucky Rock Asphalt: This material occurs as a mississipian sandstone, naturally impregnated with asphalt. It is normally placed with an initial compacted thickness of approximately ½ inch, but has been applied as a deslicking treatment at rates as low as 8 lb. per square yard (25).

A Kentucky rock asphalt surface typifies the conditions necessary for permanent skid resistance. The individual quartz grains are highly resistant to polishing, and before they have the opportunity to polish excessively they are dislodged by traffic and replaced at the surface by fresh harsh particles. This continuous rejuvenation results in excellent anti-skid characteristics of the pavement during the entire life of the rock-asphalt surface, but in so doing limits the effective life of the treatment. For high traffic conditions a ½ inch layer of Kentucky rock asphalt may be completely displaced from the wheel-track portion of the road way in somewhat less than ten years (25).

2. Silica-sand Surface Treatments: In 1955 Virginia Council of Highway Investigation and Research found sand-asphalt mixtures as an inexpensive substitute for Kentucky rock asphalt (6,17). In the short period since its development, this treatment has received wide acceptance and has been placed on some of the most heavily traveled highways in the United States, including the elevated Pulaski skyway in

New Jersey, with its 60,000 vehicles per day, and on many of the major bridges in the New York metropolitan area (25).

The port of New York authority estimates that ½ inch thick silica sand asphalt pavement will give a smooth, long wearing, skid resistant pavement and also estimates that the expected life of this depends on the volume of traffic as seven to ten years with traffic of five to seven thousand vehicles per day and four to five years with fifty to sixty thousand vehicles per day (32).

3. Additional non-skid Surface Treatments: There are many other varieties of non-skid treatments which have not been used as extensively as the two previously considered (25).

a. Vulite is a proprietory product containing asphalt emulsion, cement, sand and water. The ingredients of this material are mixed in a concrete mixer, spread and screened to a thickness of ½ inch to 3/4 inch, floated with a mechanical float and rolled with a one ton roller. An installation of this type on the George Washington Bridge appears to be exhibiting good angi-skid characteristics (23).

b. Rockite: A proprietory material called rockite is another thin surfacing asphaltic material. It contains aggregate upto one quarter inch. It is made cold, but the exact method of manufacture is not available for publication. Powdered asphalt is used in its manufacture (23).

c. Epoxy Resins: This material is a plastic developed by shell oil and the reliance steel products company of McKeesport, Pennsylvania. The chemical ingredients are mixed in the correct proportions in a flat bed truck, discharged into a hopper, and spread in strips on the bridge deck. A special paint-like roller spreads these strips into a uniform coating of the predetermined thickness. Sand is then spread over the liquid epoxy and rolled with a small one-ton roller (23). Reliance Steel Products Company and Shell Chemical Corporation (16) made studies with application of Relcote on many types of highway surfaces to eliminate the dangers of skidding and made the following conclusions.

1. Employment of proper method of removal of oil and grime deposits.

2. Use of tests to determine that the tensile strength of surface layers of the concrete is at least 150 psi. Surfaces must be treated until this minimum strength is obtained.

3. Employment of the proper grit and extenders with the epoxy resin.

4. Employment of careful workmanship with trained labor.

When these procedures are followed, it appears that such resinous cement surface treatments for highways should possess the following qualities.

1. Permanent high traction even under wet or oily conditions.

2. Long-wearing properties in hot or cold climates.

3. Excellent resistance to freezing conditions, de-icing salts, solvents and water.

4. No porosity, which protects the original pavement.

5. Light-weight, which is especially useful in resurfacing bridges, where excessive loadings in weight or thickness are undesirable.

6. Easily colored for lighting, safety or directive requirements.

7. Fast curing to give a minimum interruption of the flow of traffic.

Finally a non-skid silica-sand surface treatment, such as that developed by Virginia, will probably be the most generally accepted method of combating pavement slipperiness in the future.

CONCLUSIONS

1. In this country there are several machines designed for measuring the skid resistance both in the laboratory and the field, but there is no relationship between each other. This is leading to lot of difficulties for comparison of results and so standard testing procedure should be developed for uniform usage throughout the country.

2. Skid information should be included in the accident reports whether skidding is considered the direct cause of accident or not.

3. All states should start a program of rating highways with respect to slipperiness of the surfaces.

4. AASHO should evaluate minimum coefficients of friction and the the same used in the geometric design of highways such as curvature, grade, sight distance width and so on to minimize the accidents.

5. All states should build road surfaces which are skid proof to traffic using the findings of the skid resistance measurements on existing roads and laboratory tests.

6. Existing slippery pavements can be improved with ½ inch thick silica sand asphalt pavement.

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SKIDDING ON HIGHWAYS

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An Abstract Of

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Skidding is an important factor in highway accidents. Accidents involving directly skidding increase significantly when the coefficient of friction between the sliding tire and pavement surface is less than 0.40. The wet skid factor becomes more serious as speeds increase and traction coefficient decreases often sharply. Currently there is an appreciable mileage in the U.S.A. which cannot develop this friction value for all surface conditions and as the polishing effect of traffic becomes increasingly intensified the mileage of slippery pavement will tend to increase. All highway surfaces can develop adequate skid resistance in the dry state. In fact, all surfaces which are extremely slippery when wet exhibit excellent antiskid characteristics in the dry condition.

There are several methods for measuring skid resistance in laboratories and also in the field. Among the field experiments, stopping distance test, rate of deceleration test and towed vehicle skid tests are commonly known. For a limited accident investigation or an urban accident study in which vehicle speeds are relatively low, a passenger-car stopping distance method would be entirely adequate. If a limited study is made on rural areas or in urban areas where high vehicular speeds are anticipated it would be well to consider the use of a decelerometer, since the stopping distance method may not always be an accurate measure of skid resistance properties at high speeds. The truck trailer method is best suited of the three methods to an extensive field investigation of pavement slipperiness. The antiskid properties of a well-designed pavement surface are dependant 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 dependant 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. Since test data from various sources prove rather conclusively that limestone surface courses are inherantly responsible for slickness. If a reasonable degree of skid resistance is to be maintained on our highways for anticipated high volume of 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.

A number of methods for improving the skid resistance of slippery pavements by modifying the existing surface have been developed for the past twenty years. There are two popular non-skid surface treatments, (1) Kentucky Rock Asphalt, (2) silica-sand surface treatments. Silica sand surface treatment such as that developed by Virginia will probably be the most generally accepted method of combatting pavement slipperiness in future.

In this country, there are several machines, designed to measure skid resistance, both in the laboratory and on the field. But there is no relationship to each other. So, a standard testing procedure should be developed for uniform usage throughout the country.