

## SKID-RESISTANCE (1961)

Jas. H. Havens

We have been studying the slipperiness of roads for 6 or 8 years and have made some reports on it. In fact, about 1958 we got prepared to do a great deal of field testing -- and couldn't find any really slick roads to test or to prove our methods of test on. So, we kinda let the problem rest and devoted out attention more to roughness studies. Some of the roads we were interested in originally are now somewhat older, and we recently noticed some newspaper accounts of accidents in which slipperiness of the road was claimed to have been a contributing cause -- anyway, we thought a report on the problem would be appropriate at this time.

One road which we have been particularly interested in is the Frankfort-Louisville Road -- because it was one of the earlier surfacing jobs which used the Type B surface with 50% natural sand. Another road is the one between Mt. Vernon and Livingston. Another is one US 31 in the area of Munsfordville. Also, there was some asphalt over-lay on US 41 south of Nortonsville that was brought to our attention by the Traffic Division.

Now, I'm afraid we won't have time to go into many details, but you have the report for study if you are interested. I can show you a few things which I think are of special interest.

SLIDE 1

In making a full-stop skidding test, here is what happens: 1) traveling at 35 mph, the wheels are locked and the car slides to a stop in about 4 seconds.

The vertical scale represents the tractive or friction coefficient (this coefficient is numerically equal to the deceleration in g's -- a g being 32 ft./sec./sec.) Thus, 5 g's = 16 ft./sec./sec., etc.

At the instant the wheels are locked, there is a high peak (traction at impending skidding is higher than the traction during skidding). Traction then falls off; there is a pitching reaction of the car body which puts these waves in the curve; and then the thing settles down to a steady skid; but as the car slows down the traction forces increase, and approach another peak at zero speed. This is pretty much what happens in a "panic" stop. This curve was made with a recording decelerometer, but we don't like to do this on a routine basis because it is too dangerous.

There is a problem of course, of selecting a specific value or average value to use in describing the slipperiness of the road. We could get an average figure by measuring the skidding distance in feet and by calculating a coefficient from the formula

$$f = V^2/30S.$$

Ideally, any method of testing should represent an average of this curve or else represent some point on this type of curve. The values which we are reporting here are taken as the average low point on the curve. In this way, we can brake the car just long enough to record the low point and can then release the brakes and proceed. Of course, the pavement has to be wetted.

SLIDE 2

There are many places where it is inconvenient to perform stopping tests of any kind. This is why we tried to develop the skewed wheel thing that Bill mentioned. By forcing the front wheels to drag and by recording the force of the drag, we thought we could get a comparative measure of traction

and slipperiness.

SLIDE 3

Another comparative type of device which we have rigged up is this bicycle wheel. It has a 7-lb. weight fixed to it (here at the top). When we release a pin, the wheel takes a free spin. As the leading edge of the weight comes down, the tread contacts the pavement, and the whole weight of the wheel bears on the pavement. The higher the slip-angle then the more slippery the pavement. This thing is very easy to use, all we need is the wheel and a can of water.

END OF SLIDES

In the report both the decelerometer values and slip-angles are reported. The data has been <sup>condensed</sup> ~~condensed~~ into a table on page 27 of the report (comment) (condensed too far).

1. The Frankfort-Shelbyville Road: .43  
The Frankfort-Eastwood: 0.33 and 0.34  
(Only difference; ~~is~~ source of limestone and in asphalt content, 5.4% + 4.7%, same age).
2. Kyrock - 0.58
3. Conglomerate-sand seal (picture p. 29)
4. Type B surface, Slag aggregate; .46 and .51
5. US 41 South of Nortonville 100-degree slip,  
coefficient of friction 0.22. This road was de-slicked, I think.

Other data are there for the record.



COMMONWEALTH OF KENTUCKY  
DEPARTMENT OF HIGHWAYS  
FRANKFORT

February 22, 1962

HENRY WARD  
COMMISSIONER OF HIGHWAYS

ADDRESS REPLY TO  
DEPARTMENT OF HIGHWAYS  
MATERIALS RESEARCH LABORATORY  
132 GRAHAM AVENUE  
LEXINGTON 29, KENTUCKY

D. 1. 7.

P. 4. 2.

MEMO TO: A. O. Neiser  
Assistant State Highway Engineer

The attached report on "Pavement Slipperiness Studies (A Progress Report)," by J. H. Havens and R. L. Rizenbergs, represents primarily a summary of the work conducted in this field by the Research Division during the past year. Friction measurements have been made by: 1) deceleration readings taken while braking an automobile, 2) stress induced in a tie-rod linked to a skewed front wheel of an automobile, and 3) a wheel-type pendulum sliding over pavement surfaces. Each of these methods is described in the report.

An analysis of skid-resistance factors is presented along with the physical concepts of frictional forces. Limiting coefficients of friction for acceptable and desirable pavement standards have not been firmly established. We believe that data collected to date by the Department and other groups do indicate tentative ranges.

We have been working toward the development of the "Skewed Wheel Method" of continuously monitoring pavement frictional resistance. It appears that this type of record would be the most desirable for rating lengths of pavement. Certain mechanical problems in the load-cell itself have interrupted this work. As a result, the other two methods of evaluation were relied upon during the past year.

We plan to re-design the load-cell and to continue our research with the test vehicle this year.

Respectfully submitted

  
W. B. Drake

Director of Research

WBD:d1

Enc.

cc: Research Committee Members  
Bureau of Public Roads (3)

Commonwealth of Kentucky  
Department of Highways

PAVEMENT SLIPPERINESS STUDIES  
(A Progress Report)

by

Jas. H. Havens  
Assistant Director of Research

and

Rolands L. Rizenbergs  
Research Engineer Associate

Highway Materials Research Laboratory  
Lexington, Kentucky  
February, 1962

## INTRODUCTION

Traction or frictional resistance of tires on clean, dry pavements tends to be fairly high (coefficient of friction of 0.6 to 0.8) and to be independent of the texture of the pavement surface. In contrast, the loss of traction on a wet pavement is due entirely to lubrication effects; and, while wet friction seems to be fairly independent of the identity of the aggregate, it is extremely dependent upon the texture and porosity of the surface. Likewise, the mineralogical and lithological characteristics of the aggregates largely determine the natural texture, i.e., type of wear (coarse or fine) which the aggregate will undergo in roadway service (1).\*

A highly polished, impervious, glassy, pavement surface is considered to be extremely "slippery" when wet. A "fat" or "bleeding" bituminous surface is likewise considered to be critical in this respect because there are no escape routes available to water entrapped under the tire except through the tire treads. Thus, tires at high speed tend to "hydroplane." Whereas, some chip-seals and other "knobby", coarse-textured surfaces provide deep valleys through which water may

---

\* Numbers in parentheses refer to References in back of report.

escape, this type of surface is typically noisy. Chips in chip-seals flatten out, wear, polish and invite bleeding; large knobby aggregates tend to round, polish, and to become slick. The ideal surface, in this respect, is thought to be a fine-textured, pre-mixed, sand-asphalt, 1/4 to 1/2 in. in thickness, sealed at the bottom but relatively pervious above the seal-zone. Angular, hard, quartz sands are thought to be ideally suited for this use, although softer sands such as limestone sands may be blended therewith provided that due allowances are made for sacrificial wear -- thereby, to more-or-less continuously expose new grit to traffic.

In order to achieve the non-skid qualities sought through the use of sand-asphalt surfaces, it is obvious that a certain amount of voids must be preserved in their design. The optimum amount of voids is now thought to be in the order of 10 percent. This percentage of voids, coupled with a light but uniform application of tack coat to the existing pavement, should result in a higher asphalt content at the bottom of the sand-asphalt layer and thereby adequately seal the underlying pavement and yet preserve the desired voids in the upper zone of the sand-asphalt surface course.

### Studies of Sand-Asphalt Mixes

For many years, Kentucky has used natural sandstone rock asphalt for surfacing and de-slicking treatments. Kentucky Rock Asphalt contains 10 to 15 percent voids when compacted and provides high resistance to skidding, even when wet. This material has been used also by various research groups elsewhere as a reference or standard in skid resistance studies and, to a considerable extent, has served as a prototype in the development of anti-skid, sand-asphalt, surfacing mixtures. Deficiencies in stability of the natural material have recently imposed restrictions on its use (2). As a consequence of this, studies on sand-asphalt mixes have been instigated (3).

### Bituminous Concrete Using Natural Sand Fine Aggregate

Practices in Kentucky since 1954 have required 50 percent natural sand in certain high-type bituminous surfaces. This, of course, is in response to a desire to "build in" skid resistance. While this has apparently alleviated the slickness problem to a considerable degree, field measurements and specific data are not presently available from a sufficient number of case histories to make a proper evaluation of the actual benefit gained by this practice in comparison to other alternatives.



### Bituminous Concrete Using Sandstone Aggregate

Although originating as a study of the feasibility of using crushed sandstones as a bituminous paving aggregate, a 30-mile test pavement built in Eastern Kentucky in 1951 (4) gave promising indications of rather high anti-skid qualities. A view of this road is provided in Fig. 1. In addition, Fig. 2 presents a close-up view of the pavement surface after 7 years in service. Wear in the coarse aggregate particles is evidenced by the fact that they are now slightly recessed below the surrounding matrix. It is also apparent that the matrix is comprised largely of firmly cemented sand grains and is more resistant to wear than the coarse aggregate particles.

The coefficient of wet friction, after two years of service and as measured by the trailer method, compared favorably with sandstone rock asphalt surfaces of equivalent age and exceeded that of limestone surfaces of lesser age.

Several pavements of this type have been built more recently; and, while specific data regarding their slipperiness is not available, they exhibit the same generally sandy texture and tendency for the coarse aggregate particles to undergo coarse wear.



Fig. 1. Ky. 30, Salyersville-Jackson, Constructed with Crushed Sandstone Aggregate in 1951.

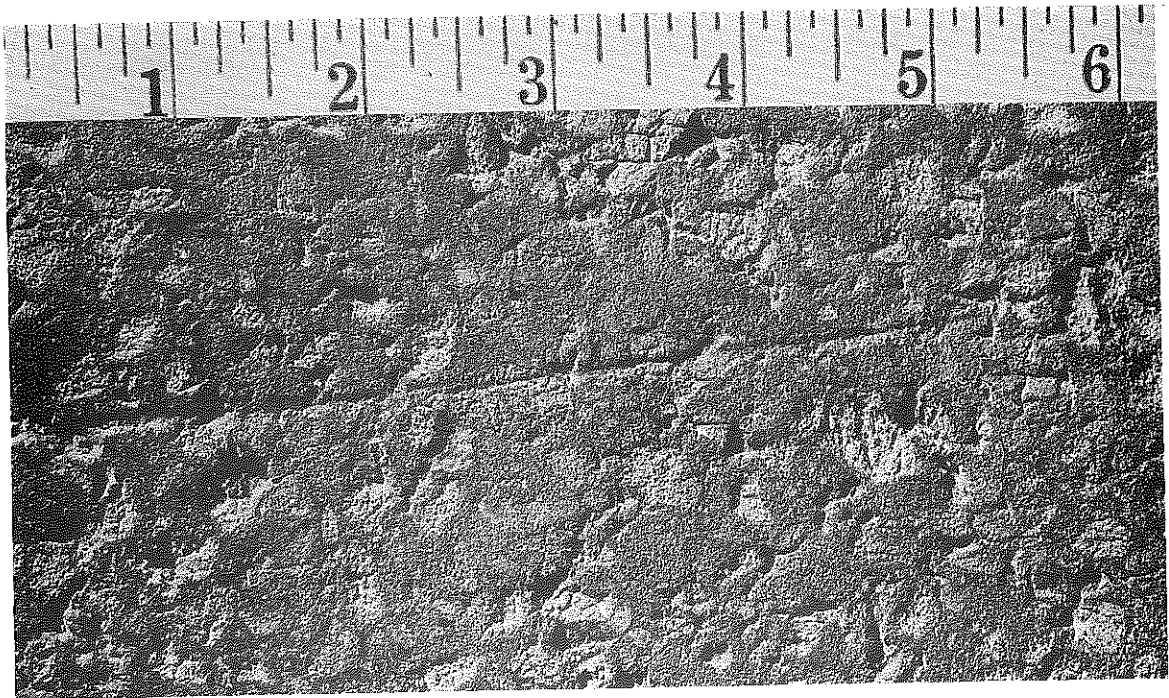


Fig. 2. Close-up View of Sandstone, Bituminous Concrete after 7 years. Note Wear of Coarse Aggregate Particles (Ky. 30, Salyersville-Jackson).

## STOPPING TRACTION: DECELERATION

Occasionally, a driver finds it expedient to decelerate at 0.4 g or higher and thus inducing a danger in unseating an unwary passenger. Likewise, the comfortable limit of cornering is about 0.3 g. However, from the standpoint of risk, the frequency of accidents due to skidding increases rapidly when  $f < 0.4$  and decreases rapidly when  $f > 0.5$  g.

When the brakes of a vehicle are locked and all wheels are sliding, the skid resistance of the pavement can be expressed by the formula:

$$F = fw$$

where:

F = frictional force and denotes the tangential force in the direction of motion,

W = normal force or weight of the vehicle, and

f = effective coefficient of friction between tires and pavement.

The acceleration or deceleration of the vehicle due to the force F is expressed as:

$$F = Ma = \frac{Wa}{g}$$

where:

a = acceleration, and

W = weight of the vehicle.

Combining these two equations gives:

$$f = a/g.$$

Thus, when a vehicle is moving in any direction with all wheels sliding or spinning, its average deceleration expressed in g's is equal to the coefficient of friction between the tires and pavement.

The most familiar equation applied to this problem is derived by equating frictional energy.  $F E = fWS$ , with kinetic energy,  $K E = 1/2 mV^2$ , from which  $fWS = WV^2/2g$  and  $f = V^2/2gS$ , where  $V$  is the maximum velocity and  $S$  is the sliding-stopping distance. Actually, in this equation  $f$  represents a theoretical value of the average traction during stopping. When  $V$  is expressed in miles per hour and  $S$  in feet, the equation becomes:

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

$$V^2 = 2 g f S$$

Note: Law enforcement agencies frequently make use of this equation in the investigation of accidents. If skid-marks are visible on the pavement, their lengths may be used to calculate the speed of the vehicle at the time the wheels began to skid.

Differentiating either frictional or kinetic energy with respect to time (work/time) gives an equation for power in which  $f$  appears as a limiting factor, and  $P = 1/2 fWV$ . Expressing  $P$  in horsepower,  $V$  in miles per hour, and assuming  $W$  to be 3850 lbs., the equation becomes:

$$HP = 5.18 fV.$$

This equation describes the time rate of the work done while skidding to a stop.

The foregoing expressions assume that all four wheels of the automobile are in traction and skidding -- which is a condition frequently encountered in a panic stop. During a maximum acceleration or "scratching off", only the rear wheels are in traction. Assuming the weight of the vehicle to be equally distributed over all four wheels, the maximum traction developed during acceleration can be expressed approximately as  $1/2 fW$ . Consequently, the maximum horsepower that can be utilized in acceleration is about half the amount used in a skidding stop on any particular pavement.

For example, from the stopping distance and horsepower equation: if  $f = .6$  and  $V = 60$  MPH, then  $S = 200$  ft. and  $HP = 187$ ; if  $f = 1.0$  and  $V = 60$  MPH, then  $S = 120$  ft. and  $HP = 310$ . Here it is seen that the maximum horsepower that could be utilized in accelerating to 60 MPH on a pavement where  $f = .6$  is 94. Similarly, when  $f = 1$  and  $V = 100$  MPH, then  $HP = 259$ .

As  $f$  approaches unity, the maximum force of friction is limited to  $F = W$ , the distance equation then becomes equivalent to  $V^2 = 2gh$ . At 60 MPH, regardless of the weight, a vehicle has enough kinetic energy to cause it to hurdle 121 ft. in a vertical direction.

The above calculations do not include the intangible factors such as driver reaction time, therefore, stopping distances are not safe stopping distances but theoretical maximums. However, the higher the coefficient of friction, the greater the guarantee of the prevention of skidding.

A vehicle entering a locked-wheel skid may experience side-skidding if there is a time differential between the locking of the front and rear wheels, if the wheels are unequally loaded, or if the pavement possesses excessive crown. The wheels which lock first transcend the impending-friction state, after which traction in the direction of travel and lateral thereto appears to subside while the wheels approaching impending-friction acquire maximum traction in both directions; consequently, the wheels offering the least tractive resistance tend to precede those offering the most resistance. Thus, an automobile with only the rear wheels locked will tend to swing the rear end around until the rear end is the leading end. The early model automobiles had rear brakes only and for that reason experienced a great deal of rear-end skidding. Unequal loading, such as on a

tractor-drawn trailer where most of the cargo is in the leading end of the trailer, can cause "jack-knifing" of the trailer because the force,  $fW$ , on the front wheels is greater than tractive resistance provided by the rear wheels.

## SKID-TESTING METHODS

Several state highway departments, institutions, private industries, the Bureau of Public Roads, and some foreign countries have measured skid-resistive properties of pavements. Methods of testing and the equipment used in testing vary considerably. Some are inexpensive and relatively simple to operate, others are bulky, expensive, and quite involved in operational procedures. The measurements obtained in all cases are not in terms of the coefficient of friction, but are in terms of the frictional force, which is a force that varies with the magnitude of friction, or in terms of the distance required for a vehicle to skid to a stop.

The most familiar method of testing is with the towed trailer having locked single, double, or triple wheels. The trailer is usually towed behind a vehicle containing measuring instruments and water supply for wetting the pavement. The vehicle is accelerated to 10-40 MPH, or higher. At the desired velocity, the trailer brakes are locked, and the force necessary to pull the trailer at a constant velocity is measured. The measured force is the frictional force; and, by knowing the weight of the trailer, the coefficient of friction is calculated. Some trailer-type devices may measure draw-bar forces which are due to partial slippage of one of the trailer wheels with respect to another -- that is two wheels turning at slightly



different speeds, both slipping slightly and creating drag. The most recent innovation in trailer-type devices is in the measurement of braking torque.

The long-popular highway test of stopping distance produces results based on the number of feet required to stop a car on a given type of pavement, and the coefficient of friction computed from the stopping distance formula. The test vehicle is accelerated to the desired velocity and then the wheels are locked. The distance required to stop the vehicle is measured. A variation of the stopping-distance test requires the use of a decelerometer -- usually of the damped-pendulum variety. The deceleration of the vehicle is measured in g's; and, since  $f = a/g$ , and since  $a/g = g's$ , the coefficient of friction is analogous to g's.

A skewed wheel, which can be added as a fifth wheel to the vehicle, is used to continuously measure the frictional properties of pavements. The skew of the wheel is set to any desired angle, with respect to the direction of travel and the side forces so created consist of one vector normal to the skew-angle, i. e. in the direction of the axle, and another in the direction of travel. Either one or both of these vectors may be monitored.

Various types of pendulums having rubber-shod, spring-loaded wipers affixed to them are used for comparing and measuring slipperiness of pavements. Recently, a device of this type, known as the British Portable Skid Tester has won considerable favor among highway engineers.

## METHODS USED IN KENTUCKY

### Friction Wheel Testing

A friction measuring device of the pendulum type developed by the National Crushed Stone Association (5), has been employed in conjunction with other methods, to be described subsequently, on most of the pavements investigated. The device consists of the front wheel of a bicycle to which a weight of approximately seven pounds is attached to the rim. Half of the circumference of the tire is ground down almost to the fabric. The axle of the wheel is supported in a slotted support which can be adjusted in heights so that the wheel turns freely when the thin-tread portion of the tire is in the low position, but when the thick portion of the tire is in contact with the road the axle is raised slightly out of its slotted support so that the full weight of the wheel then rests on the surface tested.

The test is performed by placing the device on the pavement, the area under the wheel wetted and the weighted portion of the rim brought to top-dead-center. A pin is inserted between the supports and a wheel spoke to retain exactly the same starting position for each test. The adjusting screw at the top lowers the thin portion of the tire until it just comes in contact with the pavement and then given an additional 1/8 turn to insure a free swing until tread contacts the pavement. When the pin is pulled out, the wheel accelerates freely until it comes in contact with the pavement at the thick portion of the tread.

On each surface investigated several test sites were chosen; and, at each site, ten to fifteen individual tests per wheel-track were performed at intervals of one foot apart. Because of the small weight and contact area involved between the tire and the surface tested, the tire tends to contact and bear upon the protruding aggregates or the roughened ridges. It may be deduced that well-exposed, flattened, and polished aggregates would constitute most of the tested surface.

The skid resistance of the surface is indicated by degrees of rotation through which the wheel slips after the tread makes contact with the surface. The higher the slip angle, the less skid-resistant the surface. Conveniently, each spoke of the wheel represents ten degrees, and the degree of slippage observed is recorded as the result from the test. Figure 3 illustrates the test in progress.

#### Deceleration Test

The deceleration of a vehicle, as accomplished by locking all of the wheels and skidding to a stop from a predetermined velocity; the deceleration measured in g's can be equated directly to coefficient of friction between the pavement and the tires.

The deceleration test was performed with a 1957 Ford Sedan equipped with a multi-channel Wheatstone bridge balancing unit and a recording oscillograph to provide the necessary instrumentation for



Fig. 3. Slipperiness Tester, Patterned after the National Crushed Stone Association's Goldbeck-Wheel; Consisting of a Weighted Bicycle Wheel; Adaptation of a Pendulum.

monitoring and measuring the pavement slipperiness. A horizontally sensitive, resistive-type accelerometer was used to sense the deceleration.

The procedure is to wet one lane of the pavement for a sufficient distance to make a skidding deceleration. The test vehicle is then accelerated to 35 MPH, and the wheels are locked for about three seconds. At least three tests per lane at each test site are performed, and several test locations are tested in the project under study. Figure 4 shows the test vehicle in skid over a wetted pavement.

A typical recording of a full-stop skid is shown in Fig. 5. At the instant the brakes are applied there is a rather severe reaction which takes about 1/4 second. Subsequently, the frictional forces subside, and then the curve gradually ascends to a maximum deceleration as the vehicle slows to a stop. If the skid resistance of a pavement is in excess of 0.2, a hump occurs in the curve immediately following the initial reaction, and this is attributed to pitching motion of the vehicle induced by a high impending friction.

In normal testing, only the first portion of the curve is obtained inasmuch as a full stop is not usually made. Thus, the deceleration, or coefficient of friction occurring between 25-30 MPH is taken as the measured value. This, in essence, is the lowest skid-resistance encountered during the skidding.

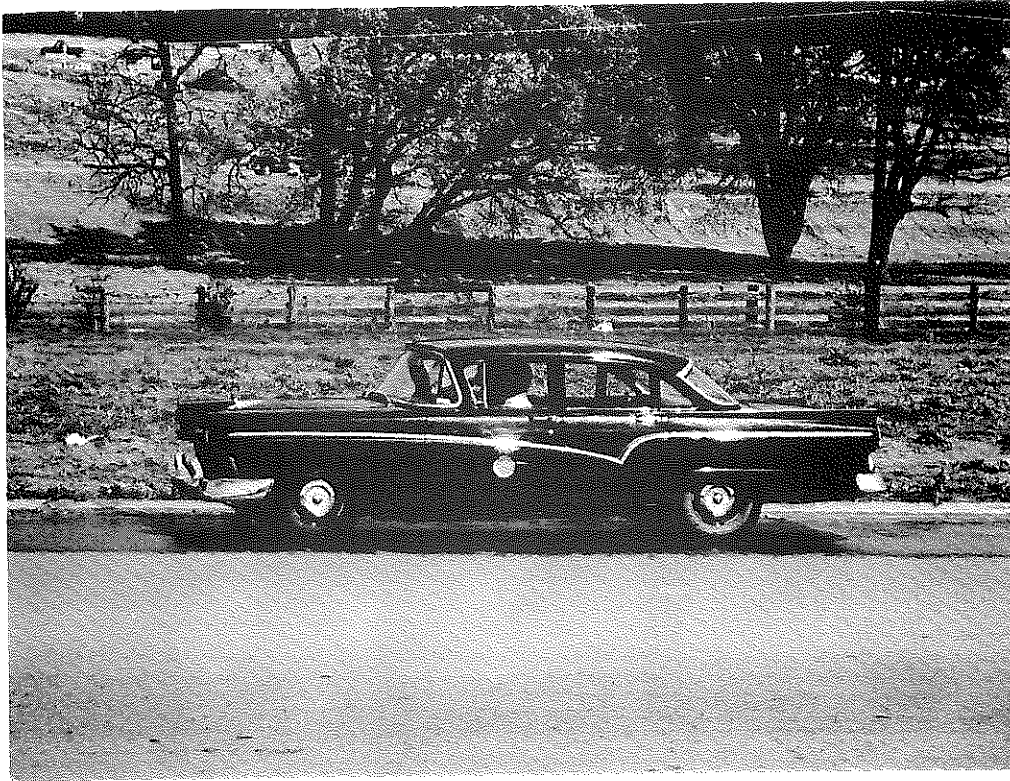


Fig. 4. Ford Sedan, 1957 Model, making a Locked-Wheel Skid on a Wetted Pavement; Car is Equipped with Decelerometers and a Recording System.

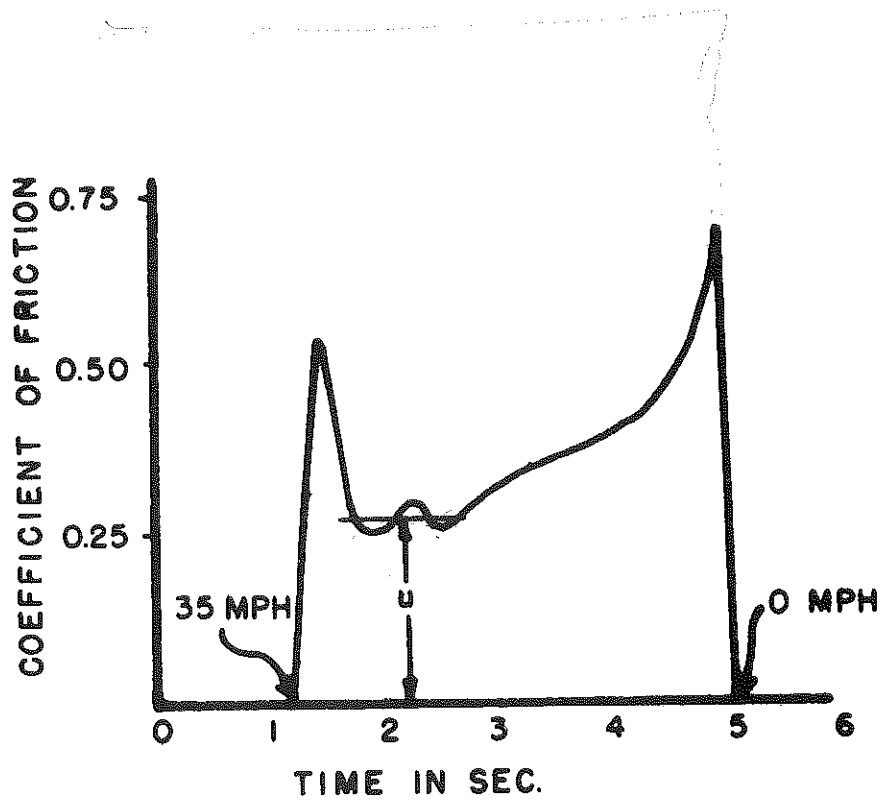


Fig. 5. Decelerometer Trace of a Locked-Wheel, Skidding Stop.



An average coefficient of friction for a complete stop would be of interest; however, the hazards involved in making a full-stop skid are dissuasive, to say the least. Testing at higher speeds would be of interest and would realistically represent normal driving conditions; however, the danger involved would be again too great for a practical or routine method of test.

#### Skewed-Wheel Test

Because of the need for continuous field testing on a variety of pavement types in Kentucky, efforts have been made to adapt a 1957 Ford automobile, already equipped with instrumentation for evaluating road-roughness (6)(7), to measure and monitor pavement slipperiness. The idea is basically that of the skewed wheel, only in this case, the skew is provided by increasing the toe-in of the front wheels. The drag induced thereby is eventually translated into compression of the tie-rod; and this compression or thrust is measured by means of a ring-type load-cell and is charted on an oscillographic recorder. The position of the load-cell is illustrated in a schematic plan view of the front wheel system of the vehicle, Fig. 6.

The normal toe-in for this vehicle is 1/16 inch measured from tread-to-tread. In trial runs, this has been increased to as much as 1-3/4 inches, but lesser degree of skew seemed more

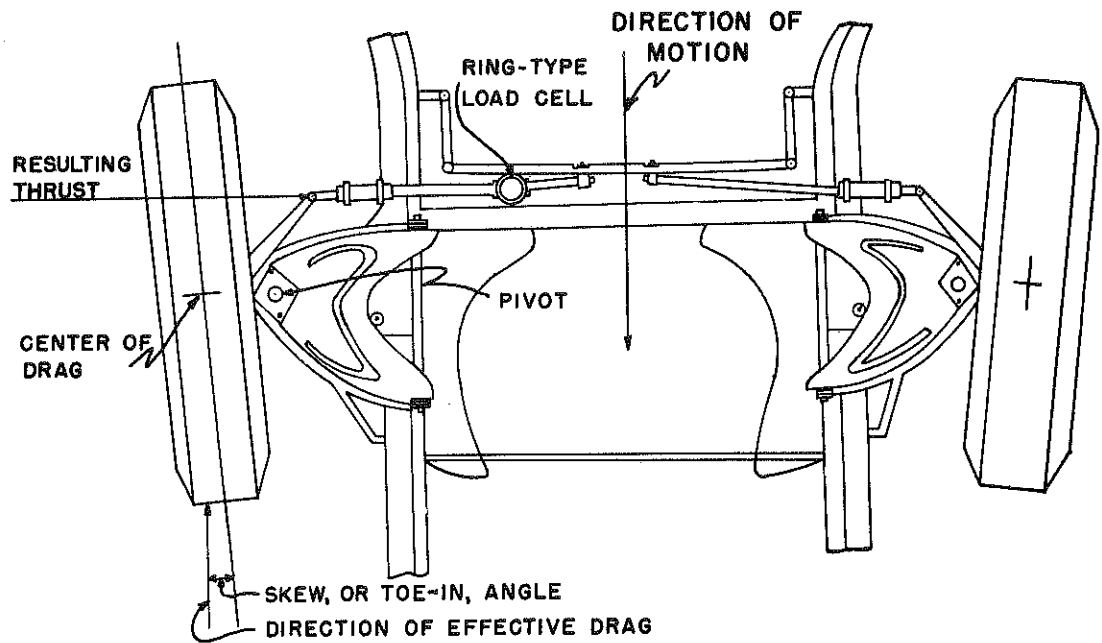


Fig. 6. Plan View of Front End of Passenger Car Showing Position of Ring-type Load Cell in Left Tie-Rod. Increased Toe-in Creates Drag which is Eventually Translated into Thrust or Compression in the Tie-Rod. Deflections Induced in the Load-Ring are Measured by SR-4 Strain Gauges. Oscillographic Recorder Permits Continuous Monitoring of Drag or Comparative Frictional Resistance.

desirable. Excessive wear on the tires must be accepted or else quick-adjusting linkages will have to be installed in each of the tie-rods to permit normal driving between measurements. As a comparative method of monitoring slipperiness, the idea offers considerable convenience, particularly if advantage is taken of rainy weather.

Technical difficulties have temporarily interrupted the use of this method in routine testing. Data obtained by this method have been reported in connection with earlier studies. By this method, the sand-asphalt surface placed on the Clark Memorial Bridge in 1958 had an apparent coefficient of friction of 0.628. The sand-asphalt surface placed on the Ashland-Coal Grove Bridge had a coefficient of between 0.595 and 0.619. US 60, just east of Middletown gave a value of 0.618 while a rock asphalt surface on US 421 between Frankfort and Midway gave a value of 0.615. On two inches of fresh snow, the coefficient dropped to 0.331; and on compacted, glazed snow the coefficient dropped to 0.148. Other data by this method appears in a research report on "Experimental Paving Projects using Curtiss-Wright's Coal-Modified, Coal-Tar Binder (First Year Performance)," by Jas. F. Hardyman, Research Engineer Associate, March, 1961.

## TESTS AND RESULTS

During 1960 and 1961, a number of Kentucky road surfaces of various types and ages were investigated for their skid-resistance properties. Some were tested as a result of newspaper accounts of accidents in which skidding on a wet pavement was reported to have been a contributing cause. Others were tested in order to compare different types of surfaces and to compare similar surfaces having different ages and service conditions. The mere suspicion of slipperiness, arising perhaps from the glassy appearance of a wet pavement or a feeling of insecurity while driving on a wet road, may have provided the incentive for making the tests in some instances. Some new pavements and particularly new Interstate pavements were tested as a matter of future reference and study.

Although it is evident that a more encompassing surveillance of this kind is needed, at the present time considerable reliance for the detection of slipperiness is based upon personal judgments and complaints arising from accidents; however, as an outgrowth of recent discussions, the Traffic Division has agreed to maintain a general surveillance over the problem and to direct attention to locations where slipperiness is suspected. It is hoped, by this means, to obtain adequate test data for defining critical pavement conditions. The use of "Slippery When Wet" signs is at best a temporary recourse.

### Kentucky Rock Asphalt Surfaces

It is of particular interest to note that Kentucky Rock Asphalt surfaces consistently retain the highest skid-resistance regardless of age, traffic, or other conditions.

### Sand-Asphalt Surfaces

There are only two instances of plant-mixed sand-asphalt surfaces being used in Kentucky. One of these was on the Clark Memorial Bridge in Louisville, and the other one was on the Ashland-Coal Grove Bridge. These were placed October 22-24, 1958, and September 14, 1958, respectively. Figure 7 shows the general appearance of the surface on the Clark Bridge after one year of service. Unfortunately, deep failures developed in the deck during the following winter, and finally the deck was sealed with wet-bottom furnace slag (Black Beauty) on October 11 and 12, 1961 (See Memo. Research Report by R. C. Deen, January 26, 1962). The sand surface on the Ashland Bridge is apparently performing very well. Comparative tests by the skewed-wheel car, indicated that the sand surfaces compared favorably with rock asphalt surfaces from the standpoint of skid-resistance.



Fig. 7. Clark Memorial Bridge, Louisville; Sand-Asphalt Surface after One Year of Service.

### Blast-Furnace Slag Aggregate

Two sections of roads containing slag aggregate in the surfaces were tested, and the results are reported in Table 1. US 60 between Cannonsburg and Ashland, appeared to contain 100 percent slag, and the average coefficient of friction was 0.51. A section of US 23, beginning near the northwest city limits of Ashland and extending toward Russell, purportedly contained slag coarse aggregate and natural sand in the surface and gave an average friction value of 0.46.

### Chip-Seals (Limestone)

Doubtlessly, chip-seals provide an economical method of surface treating lightly traveled roads; however, their value as a de-slicking treatment on heavily traveled primary roads, except possibly as a very temporary expediency, is argumentative. Some of the deterring arguments, mentioned at the beginning of this report, are concerned with the tendency for the chips to flatten, polish, and to push into the existing surface -- thereby, causing excess asphalt to bleed the surface.

Several chip-seals were applied on primary roads during the past season. Only two are cited in Table 1. They are mentioned here as a category primarily to incite interest in them and in others from the standpoint of their subsequent performance and skid-resistance.

TABLE I

Route No.	Location	County	1961 Date Tested	MCA Friction Wheel Test in Degree Slip			Densitometer Test in G's. or %			Remarks
				75 or % lanes	85 or % lanes	Combined	75 or % lanes	85 or % lanes	Combined	
<u>NEW CLASS I, TYPE B SURFACES</u>										
US 27	Cynthiana-Paris	Harrison	Sept.	85	89	87	0.40	0.38	0.39	Pavements resurfaced in 1960. 50% No. 9 Limestone, 50% Class I River Sand, 20% Class I Limestone Sand.
US 60	Fayette Co. Line- Winchester	Clark	Sept.	91	87	89	0.28	0.33	0.31	"
US 68	Harrodsburg-Perryville	Marion	Sept.	87	88	87	0.45	0.49	0.47	"
KY 11	Flemingsburg-Mt. Sterling	Bath	Sept.	87	89	88	0.48	0.47	0.48	"
KY 36	Oxhite-Bath Co. Line	Nicholas	Sept.	85	87	86	0.48	0.48	0.48	"
US 27	Cynthiana-Paris	Harrison	Sept.	95	97	96	0.36	0.36	0.36	Pavements resurfaced in 1960. 50% No. 9 Limestone, 50% Concrete Sand, 20% Limestone Sand.
US 150	Stanford-Mt. Vernon	Lincoln	Sept.	96	93	95	0.39	0.40	0.39	"
<u>OTHER CLASS I, TYPE B SURFACES</u>										
US 25	Mt. Vernon-Livingston	Rockcastle	July	98	101	99	0.24	0.33	0.29	Tested at Boles Truck Stop
US 31W	Mumfordsville-Bonnsville	Hart	August	99	93	96	-	-	-	Well polished aggregate.
US 31W	Mumfordsville-Bowlete	Hart	July	98	97	98	0.35	-	-	Tested 1.2 miles north of Mumfordsville.
US 41	Hopkinsville-Mortonville	Christian	June	-	100	-	-	0.22	-	Tested about 8 miles north of Hopkinsville.
US 60	Frankfort-Shelbyville	Franklin	July	97	100	-	0.20	-	-	0.2 miles north of "Slippery When Wet" sign.
US 60	Frankfort-Shelbyville	Shelby	June	97	94	96	0.33	0.35	0.34	About 10 miles north of Hopkinsville.
US 60	Shelbyville-Louisville	Shelby	July	84	86	85	0.43	0.44	0.43	About 3 miles north of Crofton.
KY 15	Winchester-Clay City	Clark	July	85	86	85	0.26	0.25	0.26	Asphalt 5.4%.
KY 34	Danville-Herrington Lake	Boyle	July	89	101	95	0.33	0.31	0.32	Asphalt 4.7%.
KY 34	Danville-Herrington Lake	Boyle	July	77	75	76	0.50	0.53	0.52	Just south of C.L. Winchester. Spotty bleeding.
<u>KENTUCKY ROCK ASPHALT SURFACES</u>										
US 62	Bardonia-Elizabethown	Nelson	June	-	62	-	-	-	-	Older pavement east of C.L. of Danville
US 62	East of C. L. Lawrenceburg	Anderson	June	57	-	-	0.58	-	-	Reconstructed in 1960.
US 60 & 621	West of C. L. Frankfort	Franklin	June	63	-	-	-	-	-	
<u>CLASS I, TYPE B SURFACES: SLAG AND WOLLY</u>										
US 23	Greenup-Ashland	Boyd	August	78	78	78	0.46	0.46	0.46	Pavement contains large slag particles and river sand, perhaps 50-50.
US 60	Crayson-Ashland	Boyd	August	76	77	77	0.51	0.50	0.51	100% slag aggregate.
<u>PORTLAND CEMENT CONCRETE PAVEMENTS</u>										
US 41	Hopkinsville-Mortonville	Christian	June	-	66	-	-	-	-	Five miles north of Crofton, the original surface.
US 60	Shelbyville-Louisville	Shelby	June	74	-	-	-	-	-	At C.L. Shelbyville
<u>CONCRETE-PAVEMENT SEALED SURFACING</u>										
US 25	Mt. Vernon (0.4 miles south)	Rockcastle	Sept.	76	89	83 (91 one month later)	-	-	-	Less sand in northbound lane.
	Mt. Vernon (3.0 miles south)	Rockcastle	Sept.	81	74	-	-	-	-	Large amounts of sand on roadside.
<u>NEW-BUTTON SURFACE SLAG SURFACE</u>										
US 31E	Clar: Memorial Bridge	Jefferson	Oct.	92	90	91	-	-	-	Deficiency of Aggregate in northbound lane.
<u>CHIP-SEALED SURFACES</u>										
US 119	Cumbersland-Whitesburg	etcher	Sept.	85	98	92	-	-	-	Fresh Chip-Seal surface with limestone, some scattered sandstone.
KY 15	Winchester-Clay City	Olive	July	93	97	95	0.11	0.15	0.13	Excessive asphalt on most of the surface, a well-worn and highly polished surface, tested before chip-seal in summer of 1961.



Conglomerate Sand, Seal-Type De-Slicking, US 25, Rockcastle County

Conglomerate sand (Rockcastle) has been under study for two or three years as a possible source of concrete sand (8) and as a possible alternate to natural sands usually specified for Class I, Type B surfaces. As a matter of interest here, this sand was used for a seal-type surface treatment early in September, 1961, on portions of the Mt. Vernon-Livingston road. Portions of this road had been de-slicked previously (Nov. 1960) with spinner applications of Kentucky Rock Asphalt, much of which was subsequently worn off -- i. e. in the wheel tracks. Early in the summer of 1961, some impromptu tests were made on the road using the bicycle-wheel method. These tests were reported to the Traffic Division; and, presumably as a consequence of this, some sand-seals were applied on a trial basis. The seals were applied at some of the locations that had been de-slicked previously with rock asphalt. Figure 8 shows a section of the conglomerate sand seal just north of Livingston as it appeared in late December, 1961. Figure 9 is a schematic diagram of the road and gives the approximate locations of the de-slicking treatments.

The following tabulation cites some accident statistics which were compiled by the Traffic Division and which cover a 10-month period preceeding the original de-slicking treatments and a 10-month period subsequent to the original de-slicking.



Fig. 8. Conglomerate-Sand Seal, US 25, just North of Livingston, Late December, 1961.

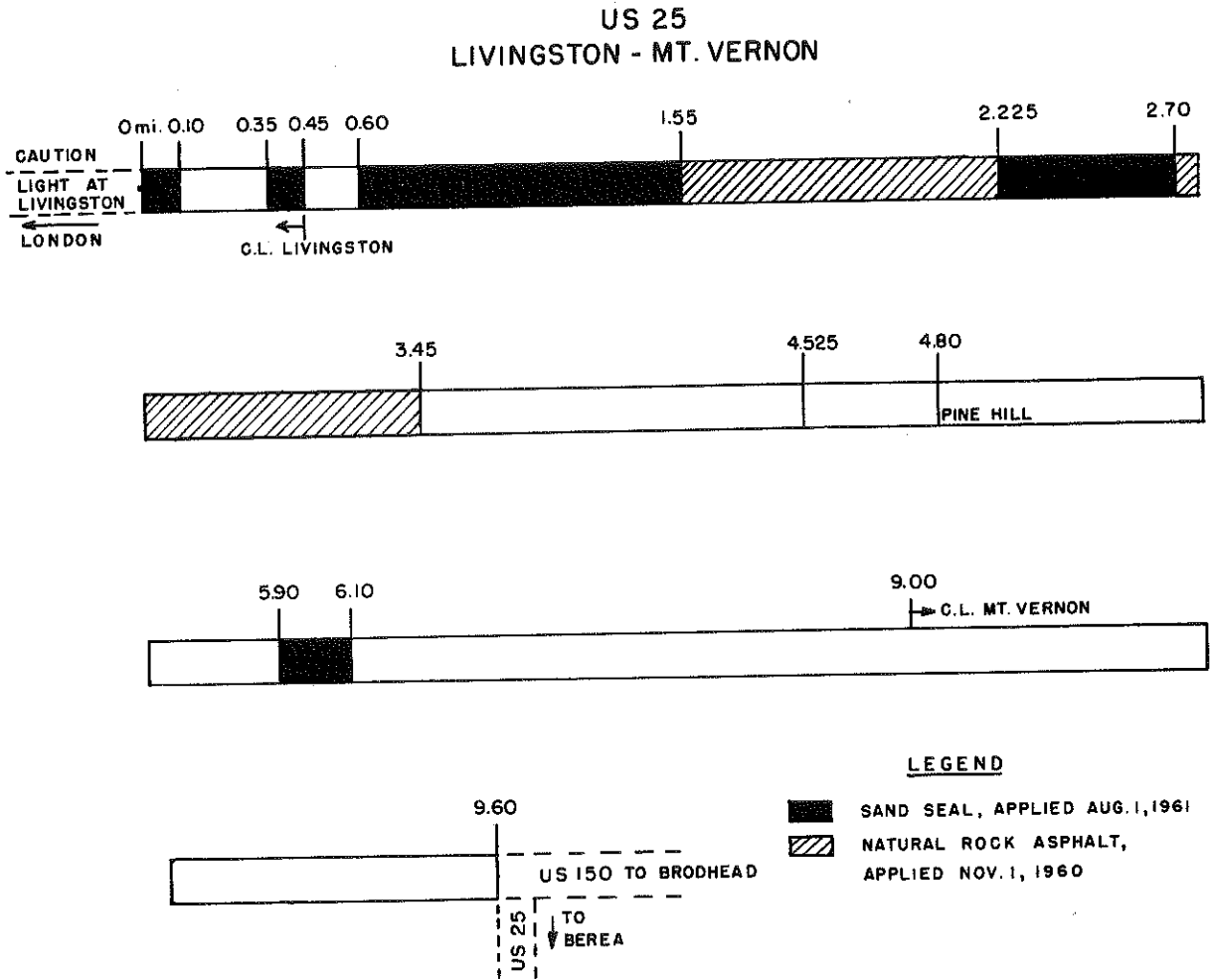


Fig. 9. Schematic Diagram Showing Approximate Location of De-Slicking Treatments on US 25, between Mt. Vernon and Livingston.

Dates	Period	Sections			Total Accidents
		Rock Asphalt	Sand- Seal	Other	
1-1-60 to 10-1-60	10 months before de- slicking	10	12	35	57
1-1-61 to 9-1-61	8 months following R. A. de- slicking	6	7	22	35
9-1-61 to 11-1-61	2 months following sand-seal application	2	2	2	7

Note: While it appears from total accidents (57 before de-slicking and 42 after de-slicking) that the treatments might have been effective in reducing accidents, it is equally apparent that the decrease in the number of accidents at the de-slicked locations was only five; whereas, the decrease at all other locations was 12. Paucity of data thus precludes a more definite analysis of the situation from this point of view.

It is evident from Fig. 8 that the sand seal gives a good appearance; and, except for some unevenness and a few ridges parallel to the direction of travel, the surface seems to be performing very well. Apparently, a considerable excess of sand was applied, as one may judge from the amount of sand now present on the shoulders. Further judgment of performance should doubtlessly be reserved until after the onset of summer weather or until the seal has undergone every opportunity to bleed. Data in Table 1 indicates that slipperiness increased somewhat during a one-month period.

### Interstate Pavements

Data given in Table 2 is included merely as a record of the initial or new combination of the respective pavements.

### Portland Cement Concrete Surfaces

In addition to the tests made on new Interstate concrete pavements, two other portland cement concrete pavements are included in Table 1. Both exhibited rather high values of skid-resistance. Also, as shown in Table 2, new portland cement concrete pavements on Interstate roads exhibited high resistance to skidding.

### Class I, Type B Surfaces

A few Class I, Type B surfaces paved in 1960 used 30 percent Class I river sand and a few contained 30 percent conglomerate sand (Table 1). After one year of service, US 60, Fayette County line to Winchester, had a coefficient of friction of 0.31. Kentucky 36, Carlisle to Bath County line, had 0.48. A 30 percent conglomerate sand surface on US 150, Stanford to Mt. Vernon, had a coefficient of friction of 0.39 and 95° slip angle. Generally, where the volume of traffic was higher, these surfaces became noticeably more slippery in this one-year period. Other Class I surfaces containing 50 percent natural sand are reported in Table 1. Those showing the greater slipperiness were, with exceptions, the older surfaces which had

TABLE 2

Project No.	County	Type Surface	I64 NGSA FRICTION WHEEL TEST IN DEGREES SLIP		Combined	Surface Texture
			SB or EB Lane	NB or WB Lane		
I64-2(6)17	Jefferson	PCC	72 77		75	smooth rough
I64-2(4)24	Shelby	PCC	75 75	72	74	very smooth rough
I64-3(4)31	Shelby	PCC	79 80 77 76		78	smooth but varies greatly rough rough, grooves not deep rough, grooves deep
I64-3 (9)37	Shelby	PCC	81 80		81	very smooth rough
I64-3(10)42	Shelby	PCC	77 77		77	very smooth smooth
I64-3(6)47	Franklin	PCC	76 77		77	very smooth smooth
I64-5(8)100	Montgomery	Bit.	71	74	73	very smooth
I64-5(7)93	Clark	Bit.	75 73	75 73	74	very smooth very smooth

been more thoroughly polished by traffic. One pavement, Ky. 15, just east of Winchester, was found to have a coefficient of friction of 0.25. This particular section of road was exceptionally fat, and slickness was obviously due to bleeding. It was subsequently chip-sealed.

As a special study item, the Division of Traffic obtained accident data for 1960 on US 60, Louisville to Frankfort, in an attempt to locate slippery sections on the road. The sections showing the highest frequency of accidents when wet were designated as areas for study. The roadway was tested in July, 1961, by the decelerometer and friction-wheel methods. The resultant frictional values and locations of testing are indicated on a scaled strip-map in Fig. 10. The darkened sections represent highest frequency of accidents occurring on a wet pavement. The accident data are also summarized for each section, and the length of each section is indicated.

On the basis of pavement frictional properties, the roadway could be divided into two long segments. The Eastwood-to-Shelbyville segment had a rather high frictional value by both methods of testing, while the Shelbyville to Frankfort segment was noticeably more slippery, but was not critically so in comparison to some other roads.

## US 60 LOUISVILLE - FRANKFORT

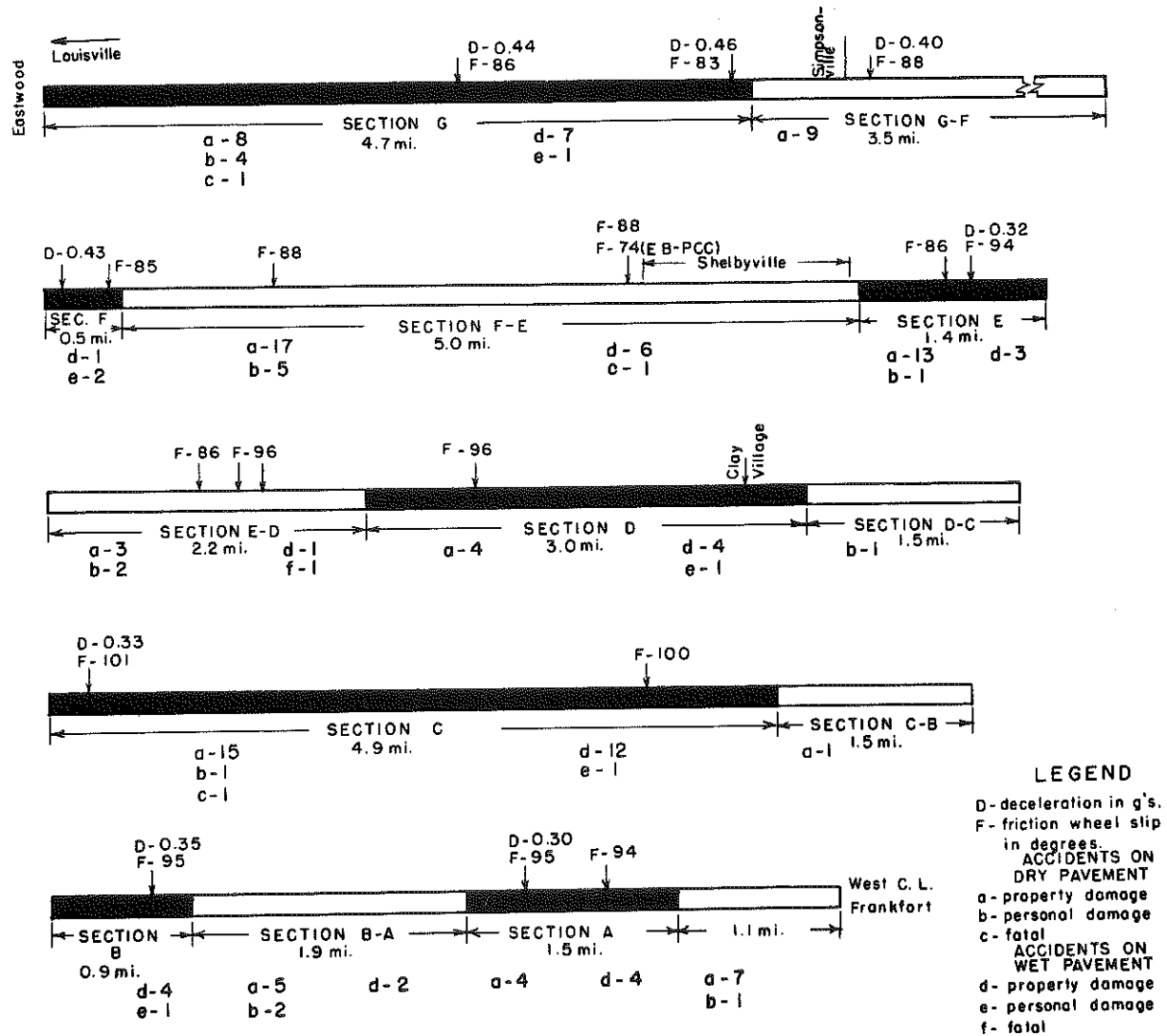


Fig. 10. Schematic Diagram of US 60, Louisville-Frankfort, Showing Locations and Types of Accidents for the year 1960, and Corresponding Results of Slipperiness Measurements.



Likewise, the accident data failed to differentiate the two sections; in this way consequently, it must be assumed that other factors were involved in the accident pattern.

Although the two segments of the Frankfort-Louisville road were constructed almost simultaneously and although the coarse aggregates were supplied from different sources (both limestone), it is of interest to note that the Frankfort-Shelbyville section was designed for 5.4 percent asphalt; whereas, the Shelbyville-Eastwood section was designed for 4.7 percent asphalt. Greater wear or loss of fine matrix (mortar) material has been observed on the Shelbyville-Eastwood section; and, doubtlessly, this accounts in part for the higher skid-resistance values obtained on that section.

## REFERENCES

1. Stutzenberger, W. J. and Havens, J. H., "A Study of the Polishing Characteristics of Limestone and Sandstone Aggregates in Regard to Pavement Slipperiness," Highway Research Board Bulletin No. 186, 1958.
2. Havens, J. H. and Williams, E. G., "A Study of the Properties and Performance of Kentucky (Natural Sandstone) Rock Asphalt," Intra-Departmental Report, Kentucky Department of Highways, February 1956 (unpublished).
3. Florence, R. L., "The Design of Thin, Silica Sand-Asphalt Wearing Surfaces for Highways and Bridges," Intra-Departmental Report, Kentucky Department of Highways, July, 1959 (Unpublished).
4. Williams, E. G. and Gregg, L. E., "Evaluation of Sandstones as an Aggregate in Plant-Mix Bituminous Pavements," Proceedings, Association of Asphalt Paving Technologists, Vol. 22, 1953.
5. Gray, J. E., "National Crushed Stone Association's Laboratory Method of Evaluating Slipperiness." Proceedings, First International Skid Prevention Conference, Part II, pp. 351-352, 1959.
6. Havens, J. H., "Skid Prevention Studies in Kentucky," Proceedings, First International Skid Prevention Conference, Part II, pp. 333-340, 1959.
7. Rizenbergs, R. L., "Pavement Friction," Kentucky Engineer, May, 1960.
8. Evans, Milton, Jr., "Rockcastle (Pottsville) Conglomerate Sand Evaluation in Portland Cement Concrete," Intra-Departmental Report, Kentucky Department of Highways, February, 1960 (Unpublished).