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Measuring of Skid Resistance
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MEASURING OF SKID RESISTANCE

1. V. A. Astrov and G. P. Filina. Instruments for Measuring the Evenness and Skid Resistance of Road Surfacing. Avtom. Dorogi (Moscow, USSR), 23 (1) 1920, 1960. (In Russian.) Road Abstracts, Vol. 27, No. 8, p 190, Aug 1960.

   An illustrated review is presented of research carried out by the USSR Road Research Institute on the design of profilometers and skid resistance meters. The MP-1 and MP-2 pendulum instruments measure the frictional resistance of the road surface to the bob of a pendulum released from a horizontal position; the limit of its swing is registered by a needle moving over a graduated arc. Three types of profilometer have been successfully developed. The "Rovnomer" tricycle profilometer has a three-meter long frame with the datum wheel mounted centrally and linked to an electronic and graphical recording mechanism. The frame of the "Volnograf" profilometer is 6 meters in length and is supported at each end by two pairs of independently sprung wheels; 12 pairs of measuring wheels mounted transversely across the middle of the frame record surface irregularity over a 3.5-m strip. A paint spray device can be attached to make sections where irregularity exceeds the acceptable limit. As these instruments can only operate at 3 to 4 km/h a trailer-mounted single wheel profilometer of the ultrasonic type has been devised. Ultrasonic impulses reflected from the road surface are recorded on an oscillograph in the towing vehicle. The same principle is applied in the M-20 instrument which records surface irregularity beneath the test vehicle and vibration in the vehicle body and chassis.

2. F. P. Nichols, Jr., J. H. Dillard and R.L. Alwood, Skid Resistant Pavements in Virginia, University of Virginia, Reprint No. 18, June 1957.

   This paper views briefly the previously published works of Moyer, Shelburne, Sheppe, and others on the subject of skid resistance characteristics. It discusses several different methods of test, and describes the method most commonly used in Virginia, the measurement of stopping distance of a passenger car with wheels locked. A discussion of the factors affecting the accuracy of this method is included.

   The results of stopping distance tests made at several hundred locations in Virginia are presented. These test results are tabulated in different ways to indicate, so far as possible, the effects of age, traffic, and most particularly, the type of aggregate used in the mix. The data point very strongly to what is felt to be a rather serious lack of skid resistance on the part of most bituminous and even portland cement concrete pavements when constructed with limestone aggregates.

A description of the experimental program designed to determine economical ways of providing non-skid pavement surfaces is given. The purpose of the experiment program was (1) to find economical ways of deslicking existing roads, and (2) to find economical ways of building-in permanent high skid resistance at the time of construction. Skid test results on the eight experimental sections are presented and discussed. The conclusions reached are tentative pending addition service life.

3. Mahone, D. C., Variation in Highway Slipperiness Characteristics with Location, University of Virginia, Reprint No. 44, May 1963.

This study compares the slipperiness characteristics of various pavement areas, some of which are not easily accessible to conventional road slipperiness measuring methods. In the study, the British portable tester was used to compare (1) slipperiness characteristics of wheel tracks with those of other lateral areas of the highway pavement, and (2) the characteristic of level tangents to those of other symmetrically shaped areas.

The 26 sites tested covered a wide range of surface types, textures and coefficients of friction. From the data obtained, it was concluded that the coefficient of friction varies both longitudinally and laterally on a highway surface. The one steel deck bridge tested was found to be extremely slippery. The lowest coefficients of friction were notes in wheel paths, on paint lines, and on bleeding asphalt spots.

4. Dillard, J. H., Measuring Pavement Slipperiness with a Pendulum Decelerometer, University of Virginia, Reprint No. 39, March 1963.

The procedure for using a pendulum-type (Tapley) decelerometer to measure the coefficient of friction is an empirical one in which the test car is braked for 1 sec and the maximum deceleration recorded by the device. The coefficient of friction determined in this way is reported to be close to the value obtained by measuring the stopping distance.

The value of the method is that it converts any car into a friction-measuring device merely by placing the self-contained decelerometer on the front floorboard of the car. Also it does not require that the test vehicle be fully stopped, hence it can be used in all but heavy traffic. Its low cost is also a great asset.

However, the relationship between the maximum deceleration during the first second and the average coefficient obtained by measuring the first second and the average coefficient obtained by measuring the stopping distance is an empirical one. Therefore, before any faith can be placed on the method when used on American cars whose suspension systems and other factors differ, the degree of correlation must be established.

In 1960, stopping distance test were run on 14 sites with 7 measurements per site. A movie camera recorded the action of a Tapley decelerometer and the deceleration data have been reduced from these films. The paper presents the data from this study and attempts to show the extent to which the empirical 1-sec braking procedure agrees with the stopping distance results.

5. Mahone, D. C., Pavement Friction as Measured by the British Portable Tester and by the Stopping-Distance Method, University of Virginia, Reprint No. 34, April 1962.

This study was made to determine whether the coefficient of friction from the stopping-distance method of measuring surface slipperiness can be predicted from measurements taken by the British portable tester on a wetted surface. Fourteen pavements were tested ranging in friction levels from dangerously low to very high and providing a wide range of surface textures. The coefficients of friction obtained by the two machines were significantly different, but the stopping-distance coefficient of friction can be predicted from measurements by the portable tester with varying degrees of precision for different stopping-distance test speeds.

6. G. G. Balmer and B. E. Colley. Laboratory Studies of the Skid Resistance of Concrete, Journal of Materials (1916 Race St., Philadelphia, Pa. 19103), Vol. 1, No. 3, pp 536-559, Sept. 1966. Highway Research Abstracts April 1967.

Procedures are developed for evaluating the potential skid resistance of concrete aggregates before casting a pavement and for the beneficiation of aggregates which polish readily. The effects of finish, exposed coarse aggregates, aggregate size, and abrasives on the skid resistance of pavements are appraised. Methods are presented for restoring friction characteristics to worn or smooth concrete.

7. Ian B. Findlay. Influence of Precoated Chippings on the Skid Resistance of Hot Rolled Asphalt, Surveyor and Municipal Engineer (40 Bowling Green Lane, London, EC1), Vol. 126, No. 3832, pp 27-30, Nov. 13, 1965. Highway Research Abstracts September 1966.

British Standard 594:1961 calls for the application of precoated chippings to hot rolled asphalt to roughen the surface, and it is generally assumed that to increase roughness is to improve resistance to skidding. The experiments described were sought a relationship between the area of stone presented to the tire and skid resistance.

For the areas tested there seems little doubt that skid resistance values tend to fall as the aggregate area increases. Thus, where the matrix itself appears to have better skidding resistance properties than the granite used for the precoated chippings, the best skid resistant values will generally be obtained where the highest percentage of matrix is exposed.

8. Robert L. Donigan and Edward C. Fisher. Vehicle Stopping Distances and Skid Marks, Traffic Digest and Review, (1804 Hinman Ave., Evanston, Ill), Vol. 11, No. 5, pp. 15-24, May 1963. Highway Research Abstracts Aug. 1963.

Previous "Know the Law" articles have discussed the current status of the law with respect to judicial notice of the factors involved in stopping distances of vehicles, and the importance of skidmarks in the field of traffic law enforcement, together with the various uses of such evidence.

Courts have frequently taken judicial notice that motor vehicles traveling at certain speeds can or cannot be stopped within given distances, although generally refusing to recognize the exact distances required for stopping in various situations.

It can now be stated with some assurance that the courts generally recognize that there is a period of reaction time - that an appreciable time elapses before the driver's purpose to apply his brakes can be transmitted from his mental process to the physical act of applying his brakes with sufficient force to slow the forward progress of his vehicle. A recent compilation of the cases so holding, with pertinent excerpts from the courts' opinions is given.

A few courts have refused to take judicial notice of the fact of reaction time or stopping distances, usually on the stated ground that such matters are not of common knowledge.

A number of courts have refused to take judicial notice of the figures shown on such tables, even though contained in official publications, holding such information is not of common knowledge.

It seems obvious that judicial approval of scientific and technological evidence of the kind herein discussed becomes more firmly established as we move farther into the motor age. It seems safe to predict at this point that the evidentiary requirements under which such evidence is now admitted may be relaxed, with characteristic judicial caution, to the point where many of the factors involved in deduction of speed from skid marks will be held matters of common knowledge and therefore proper for judicial notice, as has been the case in several States with reference to the officially prepared charts of stopping distances. As has been the case with many other matters of scientific developments and innovations in the field of law enforcement, it is at least probable that in the not-too-distant future the courts will be taking judicial notice of the mathematical process and formulae by which the speed of a vehicle may be approximated by reference to the known length of skidmarks.

9. B. Wehner, Measurements of Skidding Resistance on Slippery Roads in Winter, Strasse and Verkehr (Vereinigíng Schweizerischer Strassenfachmanner, Seefeldstrasse 9, Zurich 8, Switserland), 1960, 46 (2) 67-76. (In German) Road Abstracts, Vol. 27, No. 12, pp. 286-287, December 1960. Highway Research Abstracts, July 1961.

The measurements were carried out during the two winters 1957-58 and 1958-59 with the Stuttgart locked-wheel trailer; additional laboratory tests were made with the Leroux pendulum. The conclusions include the following: (1) The friction values obtained with the locked wheel on slippery roads in winter are largely independent of speeds. (2) There is no fundamental difference between the properties of glazed ice and silver frost. (3) The friction values are lowest at temperatures a little below the melting point of ice; they rise with decreasing temperature. This does not justify the conclusion that it is safe to drive faster at low temperatures. (4) At speeds ranging from 10 to 60 km/h and temperatures of -12.7 to 0 C, the skidding coefficients obtained by the locked-wheel trailer varied between 0.10 and 0.20 for glazed ice, and between 0.15 and 0.35 for snow compacted by traffic. (5) No optimum rate of spread of grit can be given for any of the nine materials tested. (6) Melted ice caused by the application of de-icing salts does not have the same unfavorable effect as a film of water resulting from the pressure of the tire on slippery winter road surfaces.

10. H. S. Radt, Jr. and W. F. Milliken, Jr. Exactly What Happens When an Automobile Skids? Paper No. 205A. SAE Journal (Society of Automotive Engineers, 485 Lexington Ave., New York 17, N. Y.), Vol 68, No. 12, pp. 27-33, Dec. 1960. Highway Research Abstracts, February 1961.

Steady turning and transient turning behavior of a typical automobile during a skid are among the important areas in which skid characteristics are predicted from use of a mathematical model...in recent studies at Cornell Aeronautical Laboratory.

In development of the mathematical model, the effects of camber, roll-steer, and load transfer between the wheels (from side-to-side and from front-to-rear) were considered to be negligible; as were the tire self-aligning torques. But care was taken to include smooth transition of tire side-force from zero slip angle to the maximum side-force possible.

In the problem chosen for solution, an automobile of typical proportions and weight with conventional c.g. position and tires were assumed. A friction coefficient of 0.3, representative of wet road, was chosen. Solutions were arrived at by simulation on an analog computer.

The data presented in this article were drawn from what the authors believe is the first report of "a simplified study of the smooth transition from ordinary turning to skidding behavior for automobiles."

The data result from use of a "mathematical model," which "will predict a number of experimentally verifiable skidding characteristics and may be used for either simulation or calculation purposes."

But, the authors emphasize, such an over-simplified mathematical model "is hardly suitable for detailed design use." The next step, they feel, "should be one of developing more complete models and experimentally substantiating them."

"Once a desirable level of completeness and verification has been attained," they conclude, "one can readily envision a number of specific and practical applications."

11. C. G. Giles and F. T. W. Lander. Skid-Resisting Properties of Wet Surfaces at High Speeds: Exploratory Measurements with a Small Braking Force Trailer Great Britain, Department of Scientific and Industrial Research Road Research Laboratory, Research Note No. RN/2431/CGG. FTWL, April 1955. Highway Research Abstracts, February 1956.

This report gives details of a series of exploratory tests in which skid resistance measurements have been made on the surfaces of seven runways under wet conditions at speeds up to just over 100 mph. The measurements were made with the aid of a small snngle wheel trailer towed by a powerful car, the skid resistance of the surface being assessed by measuring the braking force coefficient when the trailer wheel was locked at various speeds on the surface under test. The report gives a description of the apparatus and method of test, details of the test tires, and a description of the various runways on which the tests were made.

The results indicated that at least up to speeds of 100 mph. the skid resistance of surfaces in wet conditions follows the trends indicated by previous tests at lower speeds. In general, as speed increases the value of the coefficient falls, and at 100 mph. with a smooth tire on the various surfaces the coefficients ranged from 0.4 to 0.1 with a means of 0.24. On some surfaces a simple tread pattern on the test tire gave a useful increase in skidding resistance; the range of coefficients recorded in the present tests being from 0.5 to 0.2 at 100 mph. with the simple tread pattern that was employed.

Tests with the same apparatus on a dry runway gave coefficients of 0.7 to 0.8 at speeds up to 100 mph.

12. E. Neumann. Aufgaben des Strassenbaues bei der Sicherung des Verkehrs, VDI Zeit v 96 n 28 Oct 1 1954 p 955-9.

Design of roads with view to traffic safety; accidents due to skidding; developments in Germany for solving problems of slipperiness; measurement of roughness of pavement.

13. C. G. Giles, Skidding and Slippery Road, Instn Engrs & Shipbldrs in Scotland--Trans v 95 pt 4 1951-52 p 195-232 (discussion) 232-45.

Results of investigations into effect of vehicle, tire, and road surface characteristics on skidding; methods of measuring friction between tire and road; results show that there are big differences in performance of wet roads; connection between types of road construction, road surface texture, tire tread pattern and skidding resistance on wet roads; suggestions to eliminate skidding accidents.

14. G. Charlesworth and H. Tadman. Accidents and Road Surface, Surveyor v 109 n 3044 June 9 1950 p 329-30.

Skidding resistance measured on wood block road and, after surface was changed to machine laid hot rolled asphalt; number of skidding accidents decreased by 32%; accidents on dry roads did not change significantly.

15. I. M. Pavlov, V. K. Beloservich, E. V. Ushakov. Ustanovka dlya issledovaniya vneshnego treniya v usloviyakh plasticheskoi deformatsii metallov. Zavodskaya Laboratoriya v 27 n 4 1961 p 462-3; see also English translation in Indus Laboratory v 27 n 4 Apr 1961 p 469-70.

Apparatus for measuring external friction under conditions of plastic deformation, at high pressures and sliding velocities produced by means of fly-wheel.

16. K. H. Schulze, G. Hoffman. Bewertung der Griffigkeit von Fahrbahnmarkierungen, Strasse u Autobahn v 12 n 4 Apr 1961 p 131-6.

Evaluation of skid resistance of road marking materials; discussion of accidents by skidding on wet road markings; results of investigations by Technical Univ. Berlin, West Germany by using Leroux measuring device; skid resisting characteristics of various materials.

17. Roughness and Skid Resistance. Nat Research Council--Highway Research Board Bul n 37 Aug 1951 56 p. Following papers presented; Roughness and Skid Resistance Measurements of Pavements in California, R. A. Moyer, p 1-35 (discussion) p 35-7; Correlation of Roughometer and Skid Tests with Pavement Type, Design and Mix, A. D. Morgan, p 38-56.

18. H. O. Thompson. Road Tests Determine: What Makes Autos Skid? Eng News-Rec. v 160 n 6 Feb 1958 p 54-6, 58.

Mississippi State Highway Department measured dry and wet stopping distances on all major types of surface on state maintained system; test conditions, procedure and results obtained are given.

19. Skid Prevention Research. Nat Research Council--Highway Research Board Bul. n 219 1959; 73 p. Papers of conference at Univ. Virginia Sept 8-12 1958: Resume, T. E. Shelburne, 1-4; Accidents and Human Element in Skidding, 5-8; Relationship of Vehicle Dynamics to Skidding, 9-14; Relationship of Tire Design and Composition to Skidding, 15-20; Relationship of Road Surface Properties to Skidding, 21-4; Comparison of Methods of Measuring Road Surface Friction, J. H. Dillard, T. M. Allen, 25-51; Methods of Measuring Road Surface Friction; 52-5; Investigation of Pavement Slipperiness, J. W. Shupe, W. H. Goetz, 56-73.

20. C. G. Giles, Barbara E. Sabey, Accident Reports and Skidding Accident Sites, Public Works and Municipal Services Congress, Papers, 13, (Under the auspices of the institution of Municipal Engineers in conjunction with the Road Research Laboratory, England), November 14, 1956, 19 pp. Highway Research Abstracts, May 1957.

In dealing with problems of skidding on wet and on icy roads, police reports of accidents can be considerable value to the highway engineer.

Most skidding accidents occur when roads are wet, and road surface characteristics have their most important effect on resistance to skidding. In 1954 there were more than 13,000 personal-injury accidents in which vehicles were reported as skidding on wet roads. It is pointed out, however that the problem of skidding is mainly associated with the busiest roads;

skidding accidents show a marked tendency to cluster at the difficult sites such as traffic circles, bends, hills, and junctions on these busy roads. In some areas, up to 40 percent of all skidding accidents that have been reported in wet weather have been found to be clustered in this way at comparatively few such difficult sites on busy roads, where skidding resistance is low.

Simply by improving the skidding resistance of the road surface at these places considerable reduction in accidents have been achieved, amounting at 20 sites that have been studied, to an average reduction of 90 percent in the number of skidding accidents reported in wet weather and an over-all reduction of 45 percent in the number of accidents of all kinds occurring over comparable periods of time before and after treatment. With these reductions at typical skidding accident sites, the saving in the cost of accidents each year may well be in the order of ten times the cost of treating the road surface.

In the interests of safety the highway engineer should be in a position to recognize and treat potential skidding accident sites with the minimum of delay. To assist in this, suggestions have been made for the simple routine study of police reports of skidding accidents on wet roads, and it has been shown that by such studies substantial savings in accidents may be achieved.

Studies of the characteristics of road surface at the skidding accident sites which have been investigated have shown that rough coarse textured surfaces which are generally regarded as having a good resistance to skidding in wet weather can sometimes become quite slippery. This can unvariably be traced to the fact that the stones making up the surface have become rounded and polished under the action of traffic. At the difficult sites on busy roads where this has led to skidding accidents the effect has generally been found to occur within two years of laying the surface.

21. Accident Reports as a Guide to Slippery Lengths of Road, Gt. Brit. Road Research Laboratory, RN/2457/BES. O. R. Operational Research Quarterly (11 Park Lane, London, W. 1), Vol. 7, No. 2, pp 59-60. June 1956. Road Research Abstracts February 1957.

The note describes a simple method of detecting the more slippery lengths of road in the country, where surface treatment to improve skidding resistance could reduce accidents. Essentially, it involves studying accident reports with particular reference to the locations of accidents involving skidding on wet roads. Where clusters of skids occur the frequency of skidding is compared with some chosen standard of performance. A suitable standard would be the average rate of skidding in accidents in Great Britain; that is, the percentage of all wet-road accidents in which skidding occurs must be assessed statistically in order to make allowance for the possible effects of chance variations in the numbers of skids reported. These statistical tests are greatly simplified with the aid of a nomogram, which has been prepared to enable comparisons of frequencies to be made without the necessity for any calculations.

Use of the nomogram is illustrated by an example and the theory underlying its construction is given in an appendix.

The method described has so far been tested in two counties; twelve sites thought to need treatment have been revealed. Ten of these sites were suitably treated, and the numbers of accidents fell; the other two sites awaited treatment for several months, and during this period the police reported a marked increase in the incidence of skidding.

It is suggested that similar accident studies could usefully be made in other areas. Although such studies may not reveal all road surfaces which tend to be slippery when wet, they will at least detect those roads which, by virtue of their accident records, are most in need of attention.

22. J.H.H. Wilkes. Non-Skid Roads, Institution of Municipal Engineers (84 Eccleston Sq., London, S. W. 1), South-Western District May 1960. Civil Engineering and Public Works Review, Vol. 55, No. 652, pp 1499-1500, November 1960.

Some 8 or 10 years ago interest started to be taken in the resistance of road stones to skidding. At that time there was reasonable hope that in the fairly near future, as further information was gained, the subject would become more simple. This has unfortunately not turned out to be the case. The Road Research Laboratory has developed several tests for estimating the skidding properties of road surfaces; namely, the locked wheel test, the pendulum apparatus, and the polish stone test.

For the locked wheel test an ordinary van can be used equipped with a Tapley meter. The wheels are locked for one second, and the deceleration is measured. In the pendulum apparatus a heavy pendulum, fitted with a rubber slider, is raised to a horizontal position and released so that the slider slides over the road surface. In the polished stone test, which provides a means of measuring the polishing characteristics of the stone itself, samples of the stone are fixed on the periphery of a wheel on which runs a stone itself, samples of the stone are fixed on the periphery of a wheel on which runs a loaded rubber tire, the wheel being driven by an electric motor. The stone is fed with an abrasive in order to accelerate the polishing effect, and after the requisite time the specimens are tested under the pendulum apparatus.

Some stones polish more than others and some not at all. This polishing does not appear to be in any way dependent on the petrological characteristics. For example, some granites will polish fairly readily, others will not. Two significant points regarding the polishing of stones are the rate at which they polish, and the degree of polish ultimately attainable. The former varies with the traffic volume, while the latter is a function of the stone itself.

The meaning of texture is illustrated by the difference between an open surface, such as a carpet or an asphalt with precoated chippings, and a dense surface, such as cold asphalt, dense tar surfacing and high stone content asphalt. With treaded tires, the locked wheel test will give very similar results in both cases. With smooth tires the results will show a considerable difference. The reason for this is the presence of a water film, which lubricates the surface. If friction is not to be reduced, the water must be given a chance to escape from under the wheel.

The author discusses the accident potential of the road and emphasizes the importance of achieving a high sideways force coefficient. In this connection he points out that the value of the superelevation of a bend is surprisingly low and that a much greater advantage is obtained if the sideways force coefficient of the surface is substantially increased. For example, on an unsuperelevated bend of 225 ft radius a sideways force coefficient of the surface is substantially increased and a sideways force coefficient of 0.4 is safe at 38 mph, but a sideways force coefficient of 0.36 is required even with the maximum superelevation of 1 in 14½. With regard to future trends the author points out that modern tire treads on wet roads, and particularly on dense surfaces, have a higher resistance to skidding than treads used only a few years ago. In addition, it is to be expected that braking systems will improve. The author recommends the use of rough-textured surfaces on high-speed roads.

23. D. J. Maclean and F. A. Shergold. The Polishing of Roadstone in Relation to the Resistance to Skidding of Bituminous Road Surfacings, Great Britain Road Research Laboratory (Harmondsworth, Middlesex, England) Road Research Technical Paper No. 43, 1958, 29 pp.

This paper describes the development of a laboratory test for measuring the relative extent to which different types of stone polish under the action of penumatic-tired wheels, the application of the test to a study of the factors causing the polish, and a study of the relationship between the polishing of the stone and the resistance of skidding of the road surfacing in which it is used.

An accelerated-polishing machine has been constructed in which specimen surfaces, composed of 3/8-in. stone chippings are passed under a penumatic-tired wheel about 320 times a minute, the loading conditions being similar to those with a four-wheeled pneumatic-tired vehicle weighing about 2 tons. Tests made under a variety of conditions showed that to obtain a polishing action it was necessary for fine mineral particles to be embedded in the surface of the tire and to be introduced between the tire and the stone, the finer the particles the greater the resulting polishing effect. In the method of test finally developed the stone specimens are subjected to a three-hour run while relatively coarse sand is fed to the machine, followed by a three-hour run during which a very fine emery flour is fed. The degree of polish attained by each specimen is measured in terms of its coefficient of friction under specified conditions by means of a pendulum-type portable tester, and is expressed as a "polished-stone coefficient," which ranges from 0.3 for the most highly polished specimens to 0.8 for specimens unpolished by wear in the machine.

It was found that the values recorded by the portable tester on the stone specimens were affected by temperature: a standard temperature of 20 C ± 2 C, therefore, specified for the laboratory test. When testing stone specimens in the road surface, where it is not possible to control the temperature, day-to-day fluctuations in the values were found to be related to temperature changes.

To determine the significance of the polished-stone coefficient small areas of 3/8-in. chippings of different stones were inserted in the surface of a road carrying 60,000 tons of traffic per day. The stone specimens were found to polish rapidly and after 45 days on a straight length and after 14 days on a bend they had reached a state of polish approaching the ultimate they could attain for the given traffic condition. The extent of the polish of the different stones inserted in the road was found to correlate well with the values of the polished-stone coefficient.

Coarse-textured bituminous surfacings using a range of roadstones were laid on five roads carrying different intensities of traffic. The surfacings comprised surface dressings, rolled asphalts with coated chippings and rock non-skid asphalt surfacings, in all of which the chippings were not smaller than a nominal ½ in. Measurements of the sideway force coefficient at 30 mph of the wet surfacings were made at intervals. On the heavily trafficked roads (25,000 tons or more per day), a good correlation was obtained between the polished-stone coefficients of the stones and the sideway force coefficients after they had shown any general tendency to decrease, which generally occurred within the first two years.

On the roads carrying less than 25,000 tons per day, the evidence obtained so far shows that the rate of polish was related to the intensity of the traffic and to features of the road layout.

24. Walter B. Horne and Robert C. Dreher. Pheonomena of Pneumatic Tire Hydroplaning, U. S. National Aeronautics and Space Administration, Washington, D. C., Technical Note TN D-2056, Nov. 1963. 52 pp. (Available from Office of Technical Services, Washington, D. C., $1.50).

When runway or road surfaces become flooded or puddled with either slush or water, both aircraft and ground vehicles such as automobiles can at some critical ground speed encounter the phenomenon of tire hydroplaning. The effects of hydroplaning can be serious to these vehicles since tires under hydroplaning conditions become detached from the pavement surface and the ability of tires to develop braking or cornering traction or guiding vehicle motion is almost completely lost. Tire hydroplaning was first noticed and demonstrated experimentally about 1957 during a tire treadmill study.

Recent research on pneumatic tire hydroplaning has been collected and summarized with the aim of describing what is presently known about the phenomena of tire hydroplaning. A physical description of tire hydroplaning is given along with formula for estimating the ground speed at which it occurs. Eight manifestations of tire hydroplaning which have been experimentally observed are presented and discussed. These manifestations are: detachment of tire footprint, hydrodynamic ground pressure, spindown of wheel, suppression of tire bow wave, scouring action of escaping fluid in tire-ground footprint region, peaking of fluid displacement drag, loss in braking traction, and loss of tire directional stability. The vehicle, pavement, tire, fluid parameters of importance to tire hydroplaning are listed and described. Finally, the hazards of tire hydroplaning to ground and air-vehicle-ground performance are listed the procedures are given to minimize these effects.

A simple expression giving a good approximation for the speed at which hydroplaning takes place was reported as $V_p = 10.35$ where V_p is the velocity above which hydroplaning will take place in miles per hour and p is the tire pressure in pounds per sq. inch. From this it may be seen that an automobile with a tire pressure of less than 25 pounds per sq inch will hydroplane at less than 50 miles per hr. whereas a truck or bus with 80 lb tire pressure will be safe at over 90 mi per hr insofar as hydroplaning is concerned.

25. B. E. Sabey, Skidding Friction-Effect of Hysteresis Losses in Tyre Tread Rubber, <u>Contemporary Physics</u> v 1 n 1 Oct 1959 p 56-61.

Magnitude of friction between tire and wet road depends on physical characteristics of both road surface and tire: recent work shows that when well-lubricated rubber slides over hard surface, as in case of tire on wet road, large part of frictional resistance may arise from energy losses in rubber as it is deformed by projections in hard surfaces and then recovers; these are so-called hysteresis losses.

26. Skidding Machine Aids Research on Tires for Use in Winter, USIS Chemistry Newsletter, Vol. VII, No. 2, p. 2, March 1953. Highway Research Abstracts, July 1953.

A skidding machine which is helping rubber chemists to develop better tires for winter driving was described at the 61st meeting of the Division of Rubber Chemistry of the American Chemical Society, in Buffalo, New York. S. Wilkinson, Jr., a chemist of the Goodyear Tire and Rubber Company (Akron, Ohio), made the statement that soft tire-tread compositions provide 49 percent more traction on ice than harder ones; and that 31 percent more friction is generated by natural rubber than by some of the synthetic tread materials which have been tested so far.

The new device consists of a circular aluminum ice tray that can be rotated under blocks of rubber which are held in a framework. Sensitive measurements of the amount of friction between the rubber samples and the ice are possible. As much as 58 percent more traction can be gained by reducing the pressure between rubber and ice from 70 to 20 lb. per sq. in., under a given load, Wilkinson reported.

"Experiments to study the frictional properties of rubber on ice have in the past consisted almost entirely of tests upon tires mounted on motor vehicles, with ice-or-snow-covered highways and frozen lakes as the laboratories," Wilkinson said.

"Although these experiments have the advantage of similarity to normal conditions of use, they suffer from uncontrollable variables, such as sudden changes in temperature, deterioration of the surface of the ice, and capability of the driver. It is not uncommon, in slide-to-stop tests, to have a range of 2 to 1 in the distances which are necessary to stop a car or truck in successive trials over the same course. Such variability occurs for tests with both synthetic and natural rubber tires.

"A more sensitive laboratory test, in which the variables could be carefully controlled, would seem to be most useful. Little has been published concerning such tests. Both static and dynamic coefficients of friction have been measured for a number of compounds, an apparatus being used in which the test piece was repeatedly drawn along a linear path at a velocity of 0.48 ft. per sec. The coefficient was calculated from an average value of the frictional force. More recent experiments have used a machine in which a circular track of ice was revolved against sled-like rubber samples. The samples were lightly loaded, and were run at velocities of up to 12 ft. per sec.

"The friction of tread compounds on ice is affected, to a great extent, by the methods and conditions of measurement. As velocity of sliding is increased from 0 to about 2 cm. per sec., there is an increase in friction; after which, there is a gradual decrease with further increase in velocity.'

"Of the test variables studied, temperature has the greatest influence. At the lowest temperatures used, -22 to -40 F., the coefficient was approximately double that which is usually observed slightly below the freezing point. Friction was also found to vary with pressure. Minor differences which resulted from changes in sample shape and surface treatment were noted.

"When testing conditions were held constant, it was found that several variables in the samples themselves affected the friction. The type of rubber which was used had a definite effect. Of about equal importance was hardness. In similar compounds, the softer samples had higher coefficients of friction."

27. A. C. Gunsaulus. Stop Those Skids! SAE Journal, Vol. 61, No. 2, pp. 68-9, February, 1953. Highway Research Abstracts, May, 1953.

Trucks and buses will not skid and tractor-trailers will not jacknife, even on the most slippery roads, if each braked wheel is equipped with a new electrical device designed to prevent premature stopping of the wheels.

Skidding cannot occur as long as the wheels are kept rolling. Skidding occurs when overbraking locks the wheels so that the tires slide.

The new control device is able to prevent skidding by sensing the impending skid and then preventing it by keeping the wheel rolling.

This principle was first used in the design of an anti-skid unit for airplanes. The device has now been adapted for truck use, where it has been found most effective in preventing skids.

When overbraking takes place on a vehicle that does not have these control devices, the following sequence of events takes place, leading to the skid: (1) brake pressure on, brake torque develops; (2) brake torque exceeds wheel torque; (3) wheel begins premature slowdown; (4) wheel stops, tire slides, and skid begins.

The new device utilizes Event 3, the premature slowdown, as a warning of Event 4.

With controlled wheels, the braking sequence becomes: (1) brake pressure on, brake troque develops; (2) brake torque exceeds wheel torque; (3) wheel begins premature slowdown; (4) sensing element signals slowdown; (5) brake pressure relieved by signal; (6) brake torque decays, wheel rpm. recovering; (7) wheel rpm. recovered, pressure reapplied.

A small D. C. generator having a voltage output directly proprotional to its armature speed (24.3v, variation per 1000 armature rpm. A 4-to-1-stepup gearbox provides sufficient armature speed at low wheel speeds.

Since the power output of the sensing generator is too small to power the solenoid brake pressure valve, two electrical relays, a condenser, and a battery are interposed between the generator and the brake valve. In this way the weak sensing signal is multiplied and reinforced.

The signal received energizes the coil of the second relay and closes its switch. It thereby starts a current through the solenoid coils of the pressure valve. The second or relaying part of the system is necessary because the switch points of the current-sensitive relay used cannot carry as heavy a current as is needed to energize the solonoid. Another relay was introduced big enough to carry this solenoid current.

In the third or valving circuit, the closing of the switch in the second relay permits power from the battery to flow through the coil of the solenoid valve, closing off the flow of pressure to the brake. Whatever pressure existed in the brake chamber is released to the atmosphere.

The sensing circuit initially signaled a wheel slowdown. This signal eventually caused the brake valve to open and relieve the excessive brake pressure. Succeeding signals by the sensing circuit, while the wheel rpm. was recovering, kept the circuits energized and the brake valve open until the wheel had again reached its proper speed. When the wheel speed stabilizes and the sensing signal ceases, the brake valve again closes, admitting pressure to the brake chamber, and the cycle of control has been completed.

Based on paper presented at SAE National Transportation Meeting, Pitsburg, Oct. 23, 1952. Paper available in full from SAE Special Publications Department. Price: 50 cents to nonmembers.

28. American Road Builder. New Skid Cart Testing Device Being Used, 918 Sixteenth St., N. W., Washington 6, D. C.), Vol. 40, No. 11, p. 20, Nov. 1963.

Looking more like the losing entry in a soap box derby than an accurate testing device, a skid cart, designed to detect sections of pavement that need treatment to minimize skidding, is being tested by the New York State Thruway Authority. The machine is the invention of William J. LaFleur, former supervisor of special maintenance for the Authority.

The cart was constructed from $129 worth of materials and took 321 working hours to complete. It is said to compare favorably in accuracy with truck-towed skid-resistance trailers and portable skid testers.

The aluminum tube chassis is mounted on four rubber wheels and topped by a measuring device in the shape of twin parallelograms. Attached to this, and riding on the road surface, is a skid fitted with a section of tire tread (which presents the same area of rubber to the pavement as an automobile tire when the brakes are set).

The cart is towed with a rope and the roughness of the pavement is recorded by a pen attached to a swinging arm. Abrasive resistant of the pavement causes the arm to swing out, separating it from a line being drawn simultaneously by another pen. The distance between the two lines indicates the degree of roughness of the surface and the amount of repair needed to roughen it for safety.

29. Operation Lowdown (Winter Driving Hazards Testing), Public Safety (national Safety Council, 425 N. Michigan Ave., Chicago 11, Ill.) Vol. 50, No. 4, pp. 19-20. April 1957.

During the last two weeks in January a ten-day research project to make sinter driving safer in 37 snowbelt states was completed.

The research project was an undertaking of the Committee on Winter Driving Hazards of the National Safety Council, and its main objective was to test the difference, if any, in stopping, traction and cornering ability of the lower-looking cars using 14-in. wheels and tires as compared with 15-in. tires which have been standard for several years.

While all formal conclusions cannot be announced until data has been carefully studied by the Committee it was no secret in the Pine Lake testing grounds at Clintonville, Wis., that 1957 cars, tires and tire chains perform as well or better on ice and snow as their older, larger counterparts.

Other questions to be determined in a study of the test data cover braking distances, pulling traction and cornering abilities covering these phases of performances: effects of various tire pressures; comparative aid of snow tires and help of reinforced tire chains; effect of locking differentials; effect of smaller wheels and lower bodies in deep snow of various depths.

Facts than can now be made public follow:

1. Reducing the pressure of modern tires below the recommended normal, long believed to give more traction and to lessen danger of skidding, is a fallacy. Tests show sub-normal pressures make it worse, because treads buckle up in the middle and only outside edges of tire remain on road surface to help you stop or go.

2. Locking, or power-dividing differentials are an aid for traction because power is transferred to the rear wheel having most traction on road surface. When both wheels are on a snowy or icy grade, however, they can still spin and you may need tire chains.

3. Snow tires are improving, but reinforced tire chains are still best for reliable stop and go traction on hard packed snow or ice.

In the seven days of actual testing 16 sets of tires were put through their paces. Four sets of control tires were used and ten sets of 14-in. new tires were used by the researchers.

Each day the 16 sets were each put through a series of three test runs on each of which ten measurements were made. The average number of test measurements a day ran approximately 480 and in the seven days more than 3,000 measurements were taken.

The tests were conducted under ideal conditions with an air temperature ranging from -6 to 20 degrees.

30. Antiskid Devices on Bicycle-Type Bomber Landing Gears Make Landings Safer, Technical Data Digest, Vol. 16, No. 2, February, 1951. Highway Research Abstracts, March, 1951.

Two antiskid devices now in use on Air Force bombers may soon point the way for eliminating skidding of large ground vehicles such as air-brake-equipped tractor-trailers and busses.

One of the mechanisms is an adaptation of the Westinghouse "Decelostat," which has been used by railroads for years to eliminate skids and shorten stops. The other device, known as the "Hytrol" system, was developed by the Boeing Airplane Co., and is being produced by Hydro-Aire Inc., Los Angeles.

Need for antiskid devices in aircraft weighing 20,000 lb. or more became evident to engineers of the Aircraft Laboratory at Air Material Command Headquarters with the advent of the bicycle-type landing gear now in use on such planes as the Martin B-51 and the Boeing B-47. Both of these planes are now equipped with the antiskid devices, with future installations planned for the B-36, as well as various cargo and fighter aircraft.

The new mechanisms actually take over the pilot's job of "sensing" a skid during the landing roll. When the pilot applies the brake "fuel on," the Decelostat or Hytrol system controls the brake force in such a manner as to obtain maximum braking torque. This results in the shortest possible landing distance without skidding the wheels or causing severe tire wear.

Basically, the Hydro-Aire device is a skid-detecting mechanism which releases brake pressure during the skid condition, limiting the skid condition to a small fraction of a second. The essential units for each wheel consists of a detector, a three-way normally open solenoid valve, and an electrical time-delay circuit. If the pressure applied to the brakes is sufficient to cause skidding, the skid detector senses the skid and energizes the solenoid valve. When thus energized, the solenoid valve blocks the pressure from the pilot's metering valve to the brake and releases brake pressure. The skid detector is a flywheel mechanism that uses inertia to detect sudden changes in wheel speed.

Fundamentally, the principle of operation of the Westinghouse Decelostat is based on the relation of the deceleration rate of an energy wheel to the deceleration rate of the airplane landing wheel or axle. The 3½ lb. device measuring 6 in. in diameter is placed on the outside of each wheel and rotates directly with the wheel.

Under normal landing conditions, the Decelostat energy wheel remains synchronized with the landing wheel. When a skid develops, the energy or "fly" wheel over-travels, operating the Decelostate valve to interrupt the brake pressure and release the brakes. When the landing wheel and the Decelostat fly wheel are again synchronous, brake pressure is restored. As the airplane wheel accelerates back to its normal speed, the Decelostat again initiates a brake release to insure against full brake being applied until normal speed has been obtained. As the airplane wheel accelerates back to its normal speed, the Decelostat again initiates a brake release to insure against full brake being applied until normal speed has been obtained. As the airplane wheel acceleration rate decreases to zero, indicating normal speed, the Decelostat functions instantly to restore full brake.

Both devices are not considered "ideal" by AMC engineers Kenton Zahrt and Robert Allen who monitored tests. Neither is an automatic braking device, they add, but both are corrective aids. The new products can be incorporated into most existing aircraft where the need for such an aid has been determined. Need for such a device has very definitely been established for most bicycle-type aircraft. Tests are being planned to evaluate the use of these controls on tricycle-type landing gear.

31. C. G. Giles, Barbara E. Sabey and K. H. F. Cardew. Gt. Britain, Road Research Laboratory, Road Research Technical Paper No. 66. 28 pp. (British Information Services, 845 Third Ave., New York 22, N. Y.).

This technical paper outlines the basic principles underlying the design of the Laboratory's portable skid-resistance tester and describes the apparatus and the way in which the various requirements have been met.

Interpretation of the test results is discussed with particular reference to certain important factors connected with the design of the instrument and its method of use and with the performance of road surfaces.

The portable skid-resistance tester has been shown to be suitable for carrying out a wide variety of measurements, both on the road and in the laboratory, being particularly well adapted for use on the more rough-textured types of surface. The design of the instrument makes the readings independent of gradient, camber or crossfall.

In its performance the instrument gives readings which correlate well with the results of tests made with patterned tires skidding at speeds of the order of 30 mph. The readings have also been correlated with the risk of accidents involving skidding on any stretch of road, and a table of suggested values of skid resistance has been provided to assist in interpretation of results.

The calibration is based simply on such factors as the effective weight of the pendulum arm, the distance over which the slider is in contact with the surface under test, and the normal load on the slider. Checks made on the 200 or so machines currently in use show that with this kind of absolute calibration all the machines agree to an accuracy of ± 3 percent.

In attaining this degree of accuracy the physical properties of the rubber used for the sliders have an important role (as they do in any apparatus for studying skidding problems). A detailed specification for the resilience and hardness properties of the slider rubber insures the high standard of consistency in the readings.

32. H. W. Kummer. Correlation Tests With The Penn State Drag Tester, Rept. No. 9, Joint Road Friction Program, Pennsylvania State University and the laboratory of the National Crushed Stone Association.

A comparison of Drag Tester Models II and III indicates that both testers agree within ± 1 Drag Tester Number (DTN) when operated by the same operator. The data scatter due to different operators did not exceed ± 1 DTN when the same tester was used, suggesting that the total data scatter should not exceed ± 2 DTN when different testers are used by different operators.

The comparison of the Model III Drag Tester with the Penn State Road Friction Tester on eleven pavements of different skid resistance levels, utilizing smooth and treaded tires, shows excellent correlation at 10 mph and good correlation at 35 mph. The broadening of the correlation band with increasing speed of the trailer tester is due to the skid number - speed gradient, which begins to exert its influence at 35 mph.

The correlation with the British Pendulum Tester was excellent, as might be expected for two low-speed testing devices operating under similar conditions.

33. Glenn Balmer. Three Instruments for the Measurement of Pavement Skid Resistance, Journal of PCA Research and Development Laboratories (portland Cement Association, 5420 Old Orchard Rd., Skokie, Ill. 60078), Vol. 7, No. 2, pp. 18-23, May 1965.

The equipment and procedures employed by PCA for studying the skid resistance and wear of concrete in pavement and laboratory tests are described briefly. The laboratory rotating wheel has proved useful for the selection of materials suitable for new construction and for upgrading worn surfaces. The skid trailer is a reliable device for proof-testing the designs recommended as a result of laboratory tests and for determining whether a pavement surface has withstood wear and continues to be skid resistant. The portable pendulum is convenient for evaluation of surface condition and is useful for applications where time and expense are prime considerations. The instruments complement each other and should help to eliminate unsafe pavements.

34. Braking in Wet Reduced by 40 Percent on Acme Anti-Skid Blocks, Highways and Bridges and Engineering Works (60 Cambridge Rd., New Malden, Surrey, England), Vol. 31, No. 1485, p. 13, Jan. 23, 1963.

Work that has been going on for some time to develop new material with improved tire-gripping characteristics has now reached fruition with the introduction by Acme Flooring and Paving Co. of wood blocks surfaced with calcined bauxite grit embedded in an epoxy resin.

Tests carried out by the Road Research Laboratory have shown that stopping distance is reduced by as much as 40 percent.

This unique combination of traditional and modern materials is already making a contribution to road safety in this country, and its further use is being considered for sections of major roads, on bridges, at roundabouts and bus stops, and for aircraft runways. The manufacturers say that is is more quickly and easily laid than conventional road surfaces and can be put down as single blocks or in prefabricated sections to follow a required camber and that maintenance is localized and can be speedily carried out with much less disturbance to traffic.

Considerable interest is being expressed in other countries, particularly in the United States, in this development as not only a means to accident prevention but also because of its lasting properties it is claimed.