TEXAS TRANSPORTATION INSTITUTE

TEXAS HIGHWAY DEPARTMENT

COOPERATIVE RESEARCH

SKIDDING

in cooperation with the
U. S. Department of Transportation
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SKIDDING

1. Sabey, Barbara E. ROAD SURFACE TEXTURE AND THE CHANGE IN SKIDDING RESISTANCE WITH SPEED. Gt. Brit. Road Research Laboratory, RRL Report No. 20, 1966. 18 pp. Available from the British Information Services, 845 Third Ave., New York, N.Y. 10022. HR Abstract, July 1967.

   Past work has indicated that, on wet roads, the rate of decrease of skidding resistance with speed is largely dependent on the coarseness of the road surface texture. On smooth, fine-grained surfaces the coefficient decreases rapidly with speed, but on coarse-textured surfaces the decrease is much less rapid. Tests have now been carried out to examine more closely the way in which coefficients decrease with speed up to 80 mph and to attempt to find a quantitative measure of surface texture which will indicate the rate of fall in coefficient with speed. Two techniques of measuring texture have been examined: the "sand-patch" method from which a measure of "texture depth" can be obtained, and a new stereophotogrammetric technique which records the surface profile. A statistical correlation has been obtained between the percentage decrease in coefficient between 30 and 80 mph and the texture depth, which measures the coarseness of texture. Recommendations for texture-depth requirements for fast roads are given: to restrict the decrease to less than about 25 percent, a texture depth of more than 0.025 in. appears necessary. A better correlation with percentage decrease in coefficient is obtained by a measure of the surface profile (the profile ratio) which takes into account the shape of projections in the surface.

2. SLIPPERINESS. Bulletin de Liaison des Laboratoires Routiers, Ponts et Chaussees (58 Blvd. Lefebvre, Paris 15e), Special Number F. Nov./Dec. 1966. 231 pp. (In French). HR Abstracts, June 1967.

   Road slipperiness is discussed from a number of points of view: the surface of the road, the construction and characteristics of tires, the results of speed or weather. Possible cures are suggested for aggregate polishing. An accident survey points up the effect of weather on the roads, and helps to pinpoint areas in which anti-skid pavement design needs increased attention. A bibliographic survey on rubber friction has been prepared by the French Rubber Institute. Summaries are provided in English, German and Spanish.

3. HIGHWAY SKID TESTERS ENTHUSED OVER NEW VEHICLE. Dixie Contractor (110 Trinity Place, Decatur, Ga.), p. 92, Aug. 26, 1966. HR Abstracts, April 1967.

   A new device for skid resistance measurements is being tested by the Florida State Road Department. Complete with automatic recorder, water tank and special timing devices, the machine will provide engineers with skid resistance measurements after the tests are completed by one man. The machine is basically a truck and small trailer, which spreads water and then skids the tires on the wet pavement. During the skid, the machine automatically records the friction, giving an accurate measure of the skid resistance. Equipped with heavy duty brakes, the trailers's wheels are locked about every 500 ft, and stop-bars mounted in the brake drums indicate the amount of friction caused the the skid. Early in 1967, the trailer will be put through two weeks of comprehensive tests at an International Skid Prevention Conference at Dunnellon, Fla.

4. Valmer, G. G. and Colley, B. E. LABORATORY STUDIES OF THE SKID RESISTANCE OF CONCRETE. Journal of Materials (1916 Race St., Philadelphia, Pa. 10103), Vol. 1, No. 3, pp. 536-559, Sept. 1966. HR Abstracts, April 1967.

Procedures are developed for evaluating the potential skid resistance of concrete aggregates before casting a pavement and for the veneficiation of aggregate, aggregate size, and abrasives on the skid resistance of pavements are appraised. Methods are presented for restoring friction characteristics to worn or smooth concrete.

5. Whitehurst, E. A. and Moore, A. B. AN EVALUATION OF SEVERAL EXPANDED AGGREGATES FOR USE IN SKID-RESISTANT PAVEMENT SURFACES. Journal of Materials (1916 Race St., Philadelphia, Pa. 19103), Vol. 1, No. 3, pp. 609-624, Sept. 1966. HR Abstracts, April 1967.

The types of aggregate used in either portland cement concrete or bituminous pavements have a large effect on the skid resistant properties of pavement surfaces. Several lightweight expanded aggregates were investigated to determine their effect on skid resistance. Laboratory and field experiments performed on lightweight expanded shale surfaces indicated large increases in the skid resistance over surfaces constructed of limestone aggregates. The increase in skid resistance was almost directly proportional to the amount of expanded shale aggregate used in the surface. Preliminary cost information implied that virtually no additional cost would be incurred in the use of the expanded shale mix as opposed to the regular paving mix used in Tennessee. Available data are insufficient to evaluate the comparative durability of the expanded shale mix. However, after nearly two years of service no defects in the integrity of an experimental pavement surface were observed.

6. Dillard, J. H. ROLE OF HIGHWAY ENGINEER IN PROVIDING SKID RESISTANT SURFACES. Virginia Highway Research Council. Presented at the Highway Research Board meeting, January 1967.

Providing roads with high skid resistance when wet presents relatively few engineering problems. The requisite materials and construction practices have been known for a number of years. The widespread existence of surfaces that become slippery when wet is due to one of two causes: (a) the higher cost of surfaces that retain their high skid resistance, and (b) the lack of knowledge on the part of highway engineers that surfaces differ so widely in their wet skid resistance.

More than one-half of the 50 states do not regularly conduct skid tests and do not have a specific knowledge of the relative skid resistance of their road surfaces. There is little doubt that highway officials must face this responsibility directly. The friction between the tire and the road is crucial to the starting, steering, and stopping of a vehicle and must be sufficient to permit all of these operations to be made safely.

7. Meyer, W. E. FRICTION AND SLIPPERINESS. Pennsylvania State University. Presented at the Highway Research Board meeting, January 1967.

The current state of knowledge of the nature of friction between a viscoelastic material, such as rubber, and a textured surface, the pavement, is reviewed and related to the tire-road contact situation. The numerous variables which may alter the friction experienced by motor vehicles and measured by various methods under wet conditions is discussed. Frictional performance is further considered in the light of the frictional needs of traffic.

This overview is used to highlight what course future research must take to bring about significant improvements in the prevention of skids by both practical and economically feasible means. The question is raised whether the measurement of pavement and tire skid resistance produces the required information or if frictional behavior of the tire in slip is not the more significant criterion.

8. Carr, C. I. CONTRIBUTION OF RUBBER COMPOUNDS TO THE WET SKID RESISTANCE OF TIRES. U.S. Rubber Tire Company. Presented at the Highway Research Board meeting, January 1967.

In the course of moderate driving, wet pavements are encountered with high frequency. Vehicle speed may not be reduced markedly. A heavy demand is placed on the tire contribution to set skid resistance because of the lower friction coefficients. To improve skid resistance, it is necessary to understand the contributions from the road surface, design, and compound.

The road surface may be considered to consist of a deformation component and an abrasive component contributed by large-scale roughness and by small-scale roughness. These components can be separated in a reasonably quantitative way by measuring the wet friction of actual road surfaces with rubber samples having a wide range of hysteresis.

A linear combination of hysteresis and modulus predicts with a high degree of accuracy the relative friction of tire materials on a particular surface. Hysteresis is positively correlated with skid resistance on actual road surfaces. Modulus is negatively correlated on such surfaces but positively correlated on highly abrasive surfaces.

The most important factor which determines the contribution of a compound to friction is the glass transition temperature of the rubber. The amounts of filler and oil are next in importance. The contribution of these additives to compound friction depends on how they change the hysteresis and modulus.

9. Horne, Walter B. TIRE HYDROPLANING. National Aeronautics and Space Administration. Presented at the Highway Research Board meeting, January 1967.

This paper first discusses the build-up of fluid pressure in the tire-ground footprint region of wet pavements that can lead to three distinct types of traction loss: dynamic hydroplaning; viscous hydroplaning, or thin film lubrication; and the referted rubber skid. The paper then discusses how pavement surface texture, pavement water depth, tire tread design, vertical load, and tire inflation pressure effect fluid pressure build-up in the footprint. Finally, two promising methods for alleviating fluid pressure build-up are discussed. These methods are pavement grooving and air jets placed in front of tires.

10. Keen, H. M. TIRE DESIGNING FOR SAFETY. Dunlop Tire & Rubber Co. Presented at the Highway Research Board meeting, January 1967.

The area in which the tire maker may make the most significant future contribution to safety is in reducing the risk of skidding on wet roads. This assumes that the present low incidence of tire structural failures will be maintained, or bettered, and that the speed capability of tires will increase as required to make changes in usage.

In studying wet hold effects it is impossible to dissociate the tread design from the tread compound, and from the type of pavement. Design effect is greatest on polished fine structure surfaces and much less on open textured roads. A good design must combine ability to deal with thick films of water by effective grooving and with thin films by good wiping action of the ribs. This must be accomplished without undue sacrifice of thread life, stability or other properties.

The tire industry is stepping up its concentration of work on truck and bus tires. Reducing the present disparity in stopping ability between truck and passenger vehicles will be a major advance in safety.

11. Harris, A. J. ROAD SURFACE TEXTURE AND THE SLIPPERINESS OF WET ROADS. Road Research Laboratory, Ministry of Transport, Crowthorne, Berkshire, England. Presented at the Highway Research Board meeting, January 1967.

Friction on wet roads involves displacing enough water to permit the road surface to interact with the tire by dry contact or by deforming it through any residual water film. This interaction must produce a frictional effect. In both respects the texture of the surface, that is, the shape and size of the asperities, is of vital importance.

How far the observed tire road forces can be explained in these terms, and the implications for further research into textures, tread material properties and tread pattern design are considered.

12. Rizenbergs, Rolands L. and Ward, Hugh A. SKID TESTING WITH AN AUTOMOBILE. Kentucky Department of Highways. Presented at the Highway Research Board meeting, January 1967.

A study was conducted to evaluate the theoretical and practical aspects of using an automobile as a testing device for measurement of pavement slipperiness. Every parameter and significant event in the excursion history of a skidding automobile was measured and recorded. The resultant skid-resistance values, 25 in all, were compared and correlated. As a result of the study, the measurement of time in the velocity increment between 30 and 20 mph was selected as an interim standard test. A number of experiments were also conducted to aid in the interpretation of test results and to establish control tolerances for the standard test. The British portable tester was further evaluated on various roads in Kentucky and was found to have limited usefulness.

13. Findlay, Ian B. INFLUENCE OF PRECOATED SHIPPINGS 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. 18, 1965. HR 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 here sought a relationship betwenn 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 shippings, the best skid resistance values will generally be obtained where the highest percentage of matrix is exposed.

14. Sabey, Barbara E. ROAD SURFACE CHARACTERISTICS AND SKIDDING RESISTANCE. Journal of the British Granite and Whinstone Federation (16 Berkeley St., London, W. 1), Vol. 5, No. 2, pp. 7-20, Autumn 1965. HR Abstracts, April 1966.

Factors influencing skid resistance of road surfaces at high and low speeds are discussed. For both conditions of traffic, a road having an adequate fine-scale harshness is required; in addition, for high speed roads, a large-scale texture is needed to deform the tread of the tire. The large-scale texture provides opportunity for the drainage of water between the tire and the road surface, while the asperities provide the main source of frictional contact with the tire. Rolled asphalt surfaces are more slippery than is desirable for high speed traffic. The Road Research Laboratory is conducting experiments to improve their anti-skid properties. The hazard of spray flung up by traffic in very wet weather is also being studied, a possible solution being to provide for surface water within the wearing course itself.

15. Horne, Walter B. and Joyner, Upshar T. PNEUMATIC TIRE HYDROPLANING AND SOME EFFECTS ON VEHICLE PERFORMANCE. International Automotive Engineering Congress, Detroit, Mich., Jan. 11-15, 1965. Paper 970C, Society of Automotive Engineers (485 Lexington Ave., New York, N. Y. 10017), 1964. 40 pp. HR Abstracts, March 196(

Pneumatic tire hydroplaning is described, and related research and facilities are reviewed. Included are results from studies of conditions in a wet tire footprint area, a discussion of the influence of significant variables, and some effects of tire hydroplaning on vehicle performance. It is shown that present tire tread design techniques and pavement surface treatment can substantially alleviate hydroplaning effects on pneumatic tires over most vehicle operating speed ranges when the pavement is wet or slightly flooded. The results also show that when pavements are deeply flooded, neither the best tire tread design nor the best pavement surface treatment can prevent hydroplaning at the critical hydroplaning speed; however, the use of air jets to remove fluid from the pavement in front of the tire shows promise as a means of alleviating hydroplaning under this condition.

16. Moore, Desmond F. THE PREDICTION OF SKID RESISTANCE GRADIENT AND DRAINAGE CHARACTERISTICS FOR PAVEMENTS. Cornell Aeronautical Laboratory. Presented at the Highway Research Board meeting, January 1966.

For slick pavements, the major factor influencing the onset of skidding or hydroplaning of pneumatic tires is surface texture. To evaluate the effectiveness of this parameter in specific cases, a simple instrument called an outflow meter has been designed, constructed, calibrated and tested. The outflow meter not only compares the relative drainage abilities of road surfaces by assigning a drainage number to each, but also serves to establish the slope of the wet sliding coefficient of friction vs speed characteristic for a particular texture. In this manner, periodic testing of pavement sections with marginal slipperiness will indicate when resurfacing is necessary. Also, the extent of locked-wheel skid testing is drastically reduced by using the outflow meter.

17. McCullough, Benjamin F. and Hankins, Kenneth D. SKID RESISTANCE GUIDELINES FOR SURFACE IMPROVEMENTS ON TEXAS HIGHWAYS. Texas Highway Department. Presented at the Highway Research Board meeting, January 1966.

The selection of a minimum skid resistance for use as another guideline for surface improvements by the Texas Highway Department is discussed. This problem was approached from an accident standpoint as well as from a design standpoint, since experience on several sections of roadway indicated a sharp reduction of accidents after surface improvements.

Skid resistance and accident data were collected on 517 rural sections representing a random sample of Texas highways. The skid resistance values were obtained by use of a towed trailer employing the locked-wheel principle on artificially wetted pavements. An analysis of these data showed that the possibility of a roadway section having a high accident rate increased as the coefficient of friction decreased.

Composite skid resistances of 0.4 and 0.3 for testing velocities of 20 and 50 mph, respectively, were selected as guidelines for considering surface improvements. In addition, skid resistance values of 0.31 and 0.24 at 20 and 50 mph, respectively, were recommended as minimum values.

18. Burnett, William C. and Kearney, Edward J. STUDDED TIRES--SKID RESISTANCE AND PAVEMENT DAMAGE. New York State Department of Public Works. Presented at the Highway Research Board meeting, January 1966.

To provide increased traction on ice and packed snow, studded snow tires were introduced by tire manufacturers in 1964. The typical 7.75 x 14 tire contains about 70 studs, six of which contact the road surface at any one time. The studs consist of a 3/32-in. diameter tungsten carbide core protruding 1/16 in. from a 3/16-in. diameter steel sheath which fits very tightly in holes formed in the tread.

This investigation was performed to obtain information on the pavement damage which might be caused by studded tires. In addition, tests were conducted to determine whether the studs would increase traction on ice and packed snow and if the studed tires would be more slippery than plain treads on wet or dry pavements.

A studded snow tire and an identical snow tire without studs were mounted on the Department skid test trailer. Tests were performed by locking a trailer wheel and sliding the test tire at a constant speed of 30 mph. Over 100 tests were performed with the studded tire on ice and snow, as well as wet and dry bituminous and concrete pavements. After each test the road surface was examined for damage. The studded tires did not cause significant pavement damage and increased traction on ice about 40 percent and on packed snow about 9 percent. The studded and unstudded tires provided approximately the same amount of traction on wet or dry bare pavements.

19. White, Oscar A. and Jenkins, John C. TESTS OF STEEL-STUDDED SNOW TIRES. Oregon State Highway Department. Presented at the Highway Research Board meeting, January 1966.

Spin-in-place tests were made on portland cement concrete, asphaltic concrete, and bituminous macadam to compare the wear on pavement caused by carbide-studded tires, tire chain, and special mud and snow grip rubber tread tires. Chain caused a larger and deeper scour in some asphaltic concrete and in bituminous macadam than did studded tires. Studded tires caused deeper grooves in portland cement concrete than did the tire chain. Rubber tread caused measurable wear but much less than the studs or chain.

Multiple trip tests, consisting of 5,330 passes on a figure 8 route composed of two 76-ft circles resulted in measurable wear on asphaltic concrete. Assuming 25 percent of vehicles are equipped with studded tires, and assuming the same quality asphaltic concrete as in the test track, the wear measured in the test track would be equaled in 60 days on the Salem-Portland Freeway.

20. Lee, Allan. EFFECTS OF CARBIDE-STUDDED TIRES ON ROADWAY SURFACES. Maryland State Roads Commission. Presented at the Highway Research Board meeting, January 1966.

A field test was designed to study the effect on Maryland roads of vehicle tires for winter use equipped with carbide studs. Both truck and passenger tires were included in the tests, and both flexible and rigid pavements were included on the test loops. Two compact test loops were selected in different areas of the state. Three measurement sites were selected for each of the two pavement types at each of the two test loops; at each site five transverse lines were established across each of the wheelpaths. Steel reference markers were set for each transverse line, and pavement wear was determinid by vertical measurements to the pavement surface along these lines.

Test trucks and passenger vehicles were drawn from the Commission's pool, and the studded tires on both front and rear wheels of the vehicles were procured from local tire supply stores. A total of 10,000 circuits was made at each of the test sites.

21. Burke, John E. and McKenzie, Lloyd J. SOME TESTS OF STUDDED TIRES IN ILLINOIS. Illinois Division of Highways. Presented at the Highway Research Board meeting, January 1966.

This paper reports the result of a series of pilot tests made in Illinois in early 1965 to help evaluate the possible abrasive effects that tungsten carbide-studded tires may have on pavement surfaces. Some tests were also made to compare the stopping distances of tires with and without studs on a dry pavement surface. Data, mostly of a qualitative nature, are presented, discussed, and evaluated.

22. Balmer, Glenn. THREE INSTRUMENTS FOR THE MEASUREMENT OF PAVEMENT SKID RESISTANCE. Journal of PCA research and Development Laboratories (Portland Cement Assoc., 5420 Old Orchard Rd., Skokie, Ill. 60078), Vol. 7, No. 2, pp. 18-23, May 1965. HR Abstracts, November 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 in 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.

23. Ekse, Martin, Alexander, Daniel, and Wade, Larry. AN EVALUATION OF FLOATATION TIRES FOR USE ON LOGGING TRUCKS. Trend in Engineering (129 More Hall, Univ. of Washington, Seattle, Wash. 98105), Vol. 17, No. 2, pp. 11-18, 23, April 1965. HR Abstracts, November 1965.

Methods are developed for measurement of surface rutting, surface roughness, and impact on roadbeds caused by heavily loaded logging trucks on roads surfaced with gravel or other mineral aggregates. Numerical evaluation of these factors makes possible a direct comparison of performance between the large single or floatation tires and conventional dual tires for logging operations. Results indicate some economic advantages of the floatation tires as compared with the conventional duals for use on logging trucks operating on unpaved roads.

24. Csathy, Thomas I. SKIDDING AND SKID RESISTANCE: A REVIEW OF THE LITERATURE. Report No. 46. Materials and Research Division, Ontario Dept. of Highways (Toronto, Ont.), March 1964. 85 pp. HR Abstracts, January 1965.

This report is the result of a study of the literature dealing with the problem of vehicle skidding, with particular reference to the skid resistance of pavement surfaces. The general problem of vehicle skidding is outlined, followed by a discussion on the nature of road friction and the principles of friction measurements. Various practical methods of measuring pavement friction, such as the sideway force method, trailer devices, stopping distance method, decelerometer technique, portable instruments, and laboratory methods are reported, and certain aspects of interpreting skid resistance measurements are summarized. Road surface properties influencing skid resistance are discussed, including pavement type and finish, mix components, surface texture and possible covering, geometric design, together with the variation of surface properties due to weathering, traffic wear, and seasonal factors. Also dealt with are influencing factors associated with the vehicle, such as the properties of the tire rubber tread pattern, braking system, weight and speed of the vehicle. Finally, presently available practical means of preventing skidding accidents are pointed out, including driving skills, mechanical devices, and anti-skid road construction and maintenance.

25. Gray, J. E. and Renninger, F. A. SKID-RESISTANT PROPERTIES OF CARBONATE AGGREGATES. National Crushed Stone Association. Presented at the Highway Research Board meeting, January 1965.

Pavement skid resistance is one of the major problems facing the highway engineer today. Unfortunately, the carbonate aggregates have become almost synonymously associated with pavement slipperiness. The data demonstrate the variability in composition and performance of the aggregates included within this broad trade classification. The skid-resistant properties of the carbonate aggregates are shown to be dependent on a differential rate of wear between their constituent minerals and to vary directly with the amount of insoluble sand size material incorporated within the aggregate.

26. Giles, C. G., Sabey, Barbara E. and Cardew, K.H.F. DEVELOPMENT AND PERFORMANCE OF THE PORTABLE SKID-RESISTANCE TESTER. Gt. Britain, Road Research Laboratory, Road Research Technical Paper No. 66, 1964. 28 pp. (British Information Services, 845 Third Ave., New York 22, N.Y.). HR Abstracts, May 1964.

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 corrlate 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 had 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 $\pm$ 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.

27. Kinsey, R. D. SKIDPROOFING: DECK ROUGHENING CARRIED OUT AT NIGHT TO MINIMIZE DELAYS. California Highways and Public Works (P.O. Box 1499, Sacramento, Calif.), Vol 42, Nos. 1-2, pp. 44-45, Jan.-Feb. 1963. HR Abstracts, June 1963.

The deck of the El Cerrito Overhead in the City of Albany on US 40 was recently serrated in order to provide increased surface traction in wet weather.

The El Cerrito Overhead was originally constructed in 1936. This structure is now carrying three lanes of northbound traffic as part of a six-lane freeway. Due to very heavy traffic through this location, now in excess of 37,000 vehicles per day, the bridge deck had lost some of its surface resistance.

Experiments indicated that small grooves cut longitudinally in the deck would materially increase any traction when the surface is wet.

The roughening was performed by using a concrete bump cutter with 1/8-in. wide diamond faced saws spaced 3/16 in. apart and in a gang saw 24 in. in width. Cutting operations required twenty passes for the entire width of the bridge, which is 1,500 ft in length.

All work on the structure was performed at night commencing at 8 p.m. on Monday and completing at 6 a.m. on Saturday.

Skid resistance tests made after completion indicated that resistance had been increased with a minimum coefficient of friction of 0.26 and a maximum of

0.35, the average being 0.32. Important features of the machine operation and speeds have not been evaluated here. Costs of this method will vary as a function of the speed of operation of the equipment. In this case higher costs than usual resulted because of the nigthtime operation and heavy traffic conditions. On this project the total costs were $13,800. This represents a cost of $0.16 per sq ft.

28. Kummer, H. W. and Meyer, W. E. THE PENN STATE ROAD FRICTION TESTER, AS ADAPTED TO THE ROUTINE MEASUREMENT OF PAVEMENT SKID RESISTANCE. Pennsylvania State University. Presented at the Highway Research Board meeting, January 1963.

The skid resistance problem is restated and the need for modern and efficient skid testing equipment for routine field tests is derived. The design and operation requirements for a routine tester are defined in terms of accuarcy, ruggedness, compactness, traffic interference, and cost of operation. The design concept of the Penn State road friction tester is shown to fulfill these requirements. The trailer and towing vehicle, instrumentation and controls the calibration equipment, and method of calibration are described. Dimensions and specifications of the road friction tester, performance data and selected results of recent tests are given.

Also described is the prototype of a new portable tester developed especially for field use to supplement the large unit. The need for further work on certain aspects of the over-all skid resistance problem is outlined and specific topics are shown to demand a solution in the near future.

29. Moyer, Ralph A. CALIFORNIA SKID TESTS WITH BUTYL RUBBER TIRES AND REPORT OF VISIT TO TEN ROAD RESEARCH LABORATORIES IN EUROPE ENGAGED IN SKID PREVENTION RESEARCH. University of California, Berkeley, ITTE. Presented at the Highway Research Board meeting, January 1963.

This paper presents results of tests conducted in 1962 to show the improvements in skid resistance on wet pavements provided by the recently developed butyl rubber tires. The tests were conducted as a continuation of the 1961 California skid test program in which certain outstanding results were obtained with a new torque meter skid test trailer equipped with standard synthetic rubber tires and a butyl rubber tire. The 1962 tests verified the exceptional accuracy and the high coefficients of friction obtained with the butyl rubber tire in the 1961 tests.

A significant feature of the 1962 tests was the measurement of unusually high coefficients of friction on wet pavements after abnormally heavy rains and traffic had scoured the pavements clean and provided a coarse-grained abrasive surface. Coefficients of friction in the very high range of 0.95 to 1.05 were measured in locked-wheel braking tests with two different butyl rubber tires and of 0.80 to 0.90 in the tests with two standard synthetic rubber tires on a wet portland cement concrete pavement built in 1960. Tests on this pavement, and also on other pavements where high coefficients of friction were measured, revealed the unprecedented result in the California tests that the coefficients in the wet pavement tests were higher than the coefficients on the same pavements in the dry pavement tests. These high coefficients represented a marked improvement in the coefficients of friction measured on California pavements over the past 12 yr partly due to the improvements in skid resistance of tires, improvements in the test equipment and in the accuracy of the measurements, and in the type and condition of the pavements tested.

For a majority of the pavements tested, the coefficients of friction obtained in the wet pavement tests with the butyl rubber tires at speeds of 10 to 50 mph averaged 0.10 to 0.15 higher than the coefficients on the same pavements in tests at the same speeds with the standard 1958 and 1961 synthetic rubber tires. Thus, the results of these tests indicate that butyl rubber tires constitute an important new development which shows great promise for the prevention of skidding accidents.

Research programs in skid prevention are actively being pursued by each of the ten road research laboratories in Europe visited by the author and reported on in this paper. The research programs in England, France, West Germany and Sweden are outstanding, the skid prevention research programs in these four countries being more elaborate and more advanced than similar programs in the United States.

30. Dreher, Robert C. and Batterson, Sidney A. COEFFICIENTS OF FRICTION AND WEAR CHARACTERISTICS FOR SKIDS MADE OF VARIOUS METALS ON CONCRETE, ASPHALT, AND LAKE-BED SURFACES. National Aeronautics and Space Administration (Washington 25, D.C.), NASA Technical Note D-999, January 1962. HR Abstracts, September 1962.

An investigation was made to obtain the coefficients of friction and the wear characteristics for skids made of various metals. Simulated landings and slideouts were made at forward speeds up to 180 ft per sec on concrete, asphalt, and lakebed surfaces. The results indicate that coefficients of friction developed by wire-brush skids and some of the softer metal skids compare favorably with those developed by braked wheels with rubber tires; however, the wire brush skids and the skids made of the softer metals showed the greatest amount of wear.

31. Delsemme, A. THE POSITION IN BELGIUM WITH REGARD TO THE SKID PROPERTIES OF ROAD SURFACINGS. Paper presented at International Road Tar Conference at Harrogate, England. Roads and Road Construction (147 Victoria St., London, S.W.1), Vol. 39, No. 462, pp. 185-186, June 1961. HR Abstracts, Oct. 1961.

There is now a new situation in Belgium with regard to the slipperiness of roads; it results from the fact that the Roads Administration (over the national network of roads) demands that builders should lay road surfaces which have definite anti-skid properties. At present they insist that all new surfaces should, in all weathers and during the two years following their application, preserve a sideways force coefficient above 0.60. This is measured by means of a stradograph fitted with smooth tires, at 50 km/h (30 mph) over a very wet roadway.

Moreover, a plan is being considered which may in the future demand the following values, subject to correction when the test temperature differs from 20 C: at least 0.65 for all primary roads I (Motorways); at least 0.60 for all primary roads II (trunk roads); at least 0.55 for all national secondary roads.

These conditions have been imposed because of the number of accidents caused by skidding, which is much greater than might at first appear. Indeed, although according to police information, only 5 percent of the total number of accidents seems definitely due to this cause, it must be admitted that slippery roads contribute to a much higher proportion of road accidents, compared with other causes which are considered as primary according to the current police system of research into road accidents.

Surfacing at present being laid in Belgium can be divided into two broad categories--those which are not dense, which are characterized by more or less rapid changes in texture, and dense materials, which may have a cement or bituminous binder, in which the change is negligible. There is a third category, that of surface dressings.

From the point of view of slipperiness, the materials which are not dense are generally characterized by a surface texture which may be called "open" in which almost each individual chipping comes into contact with the wheels of passing vehicles.

Problems to be solved in this matter of skid-proof roads mainly concern dense bituminous surfacings. Studies should first of all be directed towards the effect of binders and in particular that of tars and of mixtures of tar-bitumen and of bitumen-Trinidad asphalt about which there is a dearth of information despite British and Belgian experiments. Another aim should be to gain more data on the phenomena which are dependent on composition.

One might be led to believe that the sole aim of Belgian research on anti-skid properties has been to develop compositions and processes which would confer adequate rugosity to road surfaces, to last only for the first two years of their life. This would be inaccurate because we consider firstly that a satisfactory coarse texture should be maintained throughout the whole life of the surfacing and secondly that stability should also be guaranteed for the same period. Nevertheless, since the problems are complex and the experiments necessarily long, we cannot hope to arrive at complete and conclusive solutions immediately, and for the present we must be satisfied with seeking partial solutions to remedy the current situation as quickly as possible.

32. Kullberg, Gosta. METHOD AND EQUIPMENT FOR MEASURING COEFFICIENT OF FRICTION AT INCIPIENT SKID. National Swedish Road Research Institute, Stockholm, Sweden. Presented to the Highway Research Board meeting, January 1961.

The coefficients of friction were experimentally determined for rubber tires on road surfaces in relation to slip when a wheel is braked. The method and equipment are described. The slip can be varied from 0 to 50 percent.

When measuring with this method no brake is used. The test wheel is connected to the driving wheels of a truck by means of transmission units. A variable transmission makes it possible to change continuously the gear ratio between the test wheel and the driving wheels. Thus it is possible to measure the coefficient of friction continuously on longer distances along the road.

The paper discusses the difference between the coefficient of friction at incipient skid and at locked wheel. Experimental results are presented. This method is also used to measure the behavior of winter tires.

33. Wehner, B. MEASUREMENTS OF SKIDDING RESISTANCE ON SLIPPERY ROADS IN WINTER. Strasse und Verkehr (Vereiniging Schweizerischer Strassenfachmanner, Seefeldstrasse 9, Zurich 8, Switzerland), 1960, 46 (2) 67-76. (In German). Road Abstracts, Vol. 27, No. 12, pp. 286-287, December 1960. HR 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.

34. Kullberg, G. and Kihlgren, B. INVESTIGATION OF FRICTION PROPERTIES OF WINTER TIRES AND ANTI-SKID DEVICES. Statens Veginstitut (Stockholm, Sweden), Rapport 36, 1960. 39 pp. (English summary.) HR Abstracts, May 1961.

The National Road Research Institute of Sweden since the winter of 1952--1953 undertook investigations of winter tires and anti-skid devices for motor cars. The purpose of the investigations has been to determine the grip on the road of various winter tires and anti-skid devices compared with the ribbed-pattern tread of standard tires on roads covered with ice and snow.

Two special test vehicles, which were designed and constructed by the Institute, were used for these investigations. One vehicle was equipped with one test wheel and the other with two test wheels, which could be braked by means of a device with fully controllable slip. The friction forces between the test wheels and the road were measured and recorded by means of a spring dynamometer.

Among the tested tires there were tires with mouldings consisting of transverse or angular, relatively sturdy blocks or ribs of rubber, tires with surfaces consisting of finely ribbed rubber, tires with steel inlays in the form of pieces of wire of different thickness or blow and tires with detachable steel studs. Besides, standard tires with snow chains were investigated.

The tests were carried out on ice and snow covered roads in different conditions.

It appeared from the preliminary investigations that the air pressure in the tires and the temperature of the outer surface of the tires had a certain influence on the magnitude of the friction coefficient. For a special type of tire, where the effect of the tire air pressure on the coefficient of friction has been investigated, the best grip on the road was obtained at slightly lower air pressure than recommended for the actual wheel load. The rise in temperature of the tire surface caused by lengthy driving increased the friction coefficient to some extent.

Further, these preliminary investigations showed that the driving speed only had an insignificant effect on the grip on the road, while on the other hand the effect of the slip was different for the various types of tires and at different friction levels. At a low friction level ($u = 0.1$--0.2) the slip within the range of 20--40 percent was hardly significant for the grip on the road of both standard tires and winter tires. At a higher friction level ($u = 0.3$--0.4) the friction coefficient reached its maximum at 10--20 percent slip for winter tires with heavy pattern treads. A tire, which gives the maximum coefficient of friction at a larger slip than another tire, may at braking cause less risk of locking the wheel. A locked wheel has lost its ability to steer the vehicle. Besides, a locked wheel usually causes less force of friction than a braked, still rolling wheel.

A comparison of the grip on the road of different winter tires and anti-skid devices in relation to ribbed standard tires gave different results on the various types of roads.

On icy roads all types of tires had almost as bad a grip on the road. With transversed-grooved tires and tires with steel wire inlays or studs the friction was increased to some extent. The investigations have only been carried out with completely new tires and studs. On the other hand, snow-chains gave a marked improvement, that is, a coefficient which was approximately three times higher than that of the standard tire.

On icy roads with newly fallen snow, a small but insignificant improvement in the grip on the road was obtained from different types of winter tires. With friction coefficients as low as 0.07 these roads were extremely slippery.

Thus, the investigations prove, that so-called winter tires or winterized tires do not give a noticeable better grip on ice. On the other hand, some tires with studs and, above all, snow chains give an appreciable improvement on ice, but in spite of this the friction is still considerably lower than in the summer. It is to be observed, that the Institute has had no opportunity to study the duration of this effect or the effect of more or less worn studs. However, on snow, winter tires give a certain improvement, and therefore the expression "snow tires" would be better than "winter tires," but also in this case the friction is lower than in the summer. As the friction in the wintertime is lower than in the summertime despite the use of winter tires, the only way to reduce the risk of skid accidents in the winter is to adapt the speed and the manner of driving according to the road conditions. This means that the speed on winter roads as a rule must be reduced considerably.

35. Wilkes, J.H.H. 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. HR Abstracts, May 1961.

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 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

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 change 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.

36. Gray, J. E. and Renninger, F. A. LIMESTONES WITH EXCELLENT NON-SKID PROPERTIES. Crushed Stone Journal (National Crushed Stone Association, 1415 Elliot Pl., N.W., Washington 7, D.C.), Vol. 35, No. 4, pp. 6-11, 15, December 1960. HR Abstracts, May 1961.

During the past 10 years there has been, among some engineers, a growing belief that limestone aggregates have been the cause of excessive slipperiness in some pavements. Since no method of test was readily available for determining whether or not a given limestone would become slippery, it became a practice in some areas of this country to forbid the use of limestone in the surface course of pavements.

Actually, the problem of slippery pavements has been studied in the NCSA Laboratory for several years. Realistic test sections are placed in a circular test track and their skid resistance is measured with a special device designed for this purpose. Both the circular test track and the apparatus for measuring skid resistance were fully described in the March 1959 issue of the Crushed Stone Journal.

While performing tests for skid resistance of bituminous paving mixes in the past, it has been observed that mixes containing some limestones develop excessively slippery surfaces after a relatively small amount of rubber tire traffic, while other limestone mixes exhibit excellent non-skid properties and retain these properties during extended periods of rubber tire traffic. Quite naturally, the question arose as to what properties of these limestones would cause one to provide good skid resistance while another became slippery. It is, therefore, the purpose of this article to present the results of a study that was made in an effort to answer this question.

For this program of tests, 5 limestone aggregates, each from a different source, were selected for inclusion in bituminous concrete mixes. The bituminous mixtures themselves were designed by the Marshall procedure to comply with the specifications applicable to the various states from which the aggregates were obtained. The mixes were placed in the NCSA circular track, then rolled, first with a heavy steel roller and then by a pneumatic tire roller. After thorough compaction, the test sections were subjected to thousands of passes of a wheel equipped with a rubber tire. Initially, water and fine sand were placed on the surface of the test sections as an aid to the rubber tire in wearing away the asphalt and exposing the aggregate. Later the surfaces of the test sections were cleaned and dried and the traffic was continued, using only the rubber tire so as to polish the exposed aggregate.

Since this study was conducted on a limited number of limestone aggregates using laboratory means of evaluation, no general conclusions can be drawn. However, it is believed that at least a partial answer to the question of why some limestones polish while others do not has been found. It is known from past tests that blends of limestone aggregate and silica sand in bituminous mixtures can provide surfaces with adequate skid resistance; it is also known that some cherty limestone (nodules) have been used quite satisfactorily in surface course mixtures having good skid resistance; and it is believed that the data presented here strongly indicate that a limestone possessing the properties given above could be used as the entire aggregate in surface course mixtures which would possess adequate skid resistance. The method of testing limestones for these properties is quite simple although considerable time is required for leaching the coarse particles of aggregate, but it would seem prudent to make such tests rather than reject some good material simply because it carries the name limestone.

It is hoped that these data and this discussion will stimulate others to make a more careful study of the properties of limestones to insure that the best possible use is made of available aggregates.

37. Astrov, V. A. and Filina, G. P. INSTRUMENTS FOR MEASURING THE EVENNESS AND SKID RESISTANCE OF ROAD SURFACING. Avtom. Dorogi (Moscow, USSR), 23 (1) 19-20, 1960. (In Russian.) Road Abstracts, Vol. 27, No. 8, p. 190, August 1960. HR Abstracts, March 1961.

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 mark 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.

38. Radt, H. S., Jr. and Milliken, W. F., 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. HR 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 at zero slip angle up 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 a 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."

39. BUS TIRE SKID TESTS. Raleigh, N.C., January 1960 and Baltimore, Md., June 1960. Sponsored by National Association of Motor Bus Owners (839 17th St., Washington 6, D.C.) 25 pp. + 27 pp. Mimeo. HR Abstracts, February 1961.

The purpose of the Raleigh, N.C. test was to evaluate the stopping ability of various types of traction treatment on bus tires, comparing new original tread design with different types of regrooved and siped designs plus smooth tires

The results of these tests on this uniform new wet asphalt road surface clearly demonstrates that the controlling and stopping ability of used tires with various traction treatments were comparable to that of new original design tires.

The differences in control and stopping ability of the various tires tested were negligible when compared to the greater stopping distance required for an increase in spedd of as little as 5 mph.

Recommendations: (1) Intercity bus operators should conform at all times with ICC regulation regarding condition of tires: "No bus shall be operated on any tire which does not have tread configurations on that part of the tire which is in contact with the road surface." (2) Intercity bus operators should continue with renewed effort, driver educational programs which emphasize that the maximum difference in stopping distances due to tire tread configurations is:

(a) small compared to the difference due to increased speed, and (b) far out-weighed by the tremendous variation in the slipperiness of highway paving surfaces.

The purpose of the Baltimore, Md. report was to evaluate the stopping ability of various types of traction treatment on bus tires; comparing new original tread design with different types of regrooved and siped designs plus smooth tires at the highest possible speed at which the bus could be controlled at this particular test site.

The results of these tests on this uniform new wet portland cement concrete road surface clearly demonstrate that (1) the stopping ability of used tires with various regrooved traction treatments was comparable to that of new original design tires; (2) the increase in stopping distances due to increases in speed of as little as 5 mph is more significant than the differences in stopping distances between new and regrooved tires; (3) tread configurations on tires, either mold design, or regrooved traction treated, are essential for safe operation of intercity buses; and (4) observation of driver efforts indicated that more alertness on the driver's part was required to control the bus, when stopping at speeds in excess of 45 mph.

Recommendations: (1) Intercity bus operators should conform at all times with ICC regulation regarding condition of tires: "No bus shall be operated on any tire which does not have tread configurations on that part of the tire which is in contact with the road surface." (2) Intercity bus operators should continue, with renewed effort, driver educational programs which emphasize that the maximum difference in stopping distances due to tire tread configurations is: (a) less when compared to the difference due to increased speed, and (b) far out-weighed by the tremendous variation in the slipperiness of highway paving surfaces.

40. Leathers, Rex C. and Ian Kingham. SKID-STUDIES--AASHO ROAD TEST. AASHO Road Test, Highway Research Board, Presented at the Highway Research Board meeting, January 1961.

A series of six studies conducted periodically throughout the traffic testing period on the AASHO Road Test offered the opportunity to relate the effect on skidding resistance of a number of variables. The design of the skid resistance experiment and the controlled features of the Road Test made possible the isolation of these variables. Various plots, diagrams and charts show the effect on resistance to skidding of number of applications, magnitude of load, number and spacing of axles, pavement design, and speed of the testing vehicles. Certain seasonal or weather effects are also indicated.

41. DeFrance, I. A. SLICK PAVEMENT SURFACES MADE NON-SKID. Rural Highways (Gillette Publishing Co., 22 W. Maple St., Chicago 10, Ill.), Vol. 9, No. 6, pp. 25, 46-47, 51, November-December 1959. HR Abstracts, March 1960.

Slick pavement surfaces that, it was claimed, caused several accidents and some fatalities were not exactly new to the Oregon State Highway Department. As long as 30 years ago signs were placed at particular locations that read "Pavement Slippery When Wet or Frosty." Recent increased numbers of accidents and complaints served to make the Department aware of the growing seriousness of the slick pavement hazard under present fast driving and heavy traffic conditions. The solution to this problem has been to restore the non-skid properties to these old pavements and oiled roads by burning the flushed, excess bituminous material off the surface. The first approach, however, was to sand the flushed bituminous or oiled areas. Special shifts were organized for round-the-clock sanding; in some cases salt and calcium chloride were used as well. At the same time, a stop-gap type of burning that was tried out was very effective the burning of transverse strips across the slick surface with patch-kettle torches. The success of this work led through investigations and experimental work to the design of a pavement surface burner.

Many sections of pavement and oil were burned to observe the results and to search for damaging effect. It was learned that when torches were applied long enough to burn the surplus asphalt the asphalt and rock mixture below was protecte from burning by its rock content. As long as the burning period was short no damage was done.

Then began the design of specialized equipment for the express purpose of burning excess asphalt and which would afford positive speed control to avoid damage to the highway surface. The final design included the following:

1. A flatbed truck geared down by the addition of 2 standard 4-speed transmissions, one behind the other, to permit a smooth operation at speeds of from 6 ft per min to 45 mph.

2. A hood 8 ft wide mounting five 8-in. propane torches was placed vertically to provide a powerful down draft that would actually burn to cinders the excess asphalt as it passed over it at speeds varying from 10 to 36 ft per min.

The operation of the unit requires 4 men, a truck driver, a burner operator, and 2 flagmen; surprisingly the same number required for strip burning. At present five of the new pavement burners at a cost averaging $3,500 each, exclusive of truck, are now in use. All 5 units are operating to good advantage, averaging a mile of 2-lane highway a day.

It is anticipated that burning will have to be done each year and plans have been made to operate continuously except possibly during the early fall fire season. Cost has averaged $230 per mi of 2-lane highway. It may be possible to reduce this cost slightly during the summer months when burning speed will increas over winter burning speed. It is also hoped that the cost may be reduced when success has been obtained in extending the service life of the burner hoods. The cost of burning, however, will be offset, at least partially, by a saving from a reduced amount of sanding required.

The burning presents a certain hazard to traffic, but the 8-ft hood with the flame confined by long side panels does not seem to bother traffic. On some narrow roads the hood is raised had the torches are shut off while gas trucks and school busses pass.

42. Stephens, Jack E. and Goetz, William H. DESIGNING FINE BITUMINOUS MIXTURES FOR HIGH SKID RESISTANCE. Presented at the Highway Research Board meeting, January 1960.

This laboratory study presents the results obtained on a wide variety of sand mixes with the laboratory skid resistance machine developed earlier at Purdue University. Variables in the study include mineral composition, particle shape, and gradation of the aggregate composing these fine bituminous mixtures.

It has been determined that the laboratory relative resistance value (skid resistance) of a fine bituminous pavement mixture is closely related to the aggregate characteristics which determine the surface texture of the mixture. Mineral Composition of the aggregate is important in determining the surface character of the aggregate particles and, as such, affects the relative resistance value of the pavement. Mixtures made from angular silica sand exhibited initially higher skid resistance than those made from rounded silica. But these sharp edges were not maintained, so that, after a degree of wear, mixtures made with rounded aggregate showed superior results.

Aggregate gradation is a most important factor and shows much promise as a control for determining the skid resistance quality of pavements. Higher skid resistance values were found for the mixtures made from finer gradations. Fineness modulus can be used for predicting skid resistance values, but different curves must be used as the maximum aggregate size changes.

43. Gray, J. E. and Goldbeck, A. T. SKID PROOFING OF ASPHALTIC CONCRETE PAVEMENT SURFACES. Crushed Stone Journal (National Crushed Stone Association, 1415 Elliott Pl., N.W., Washington 7, D.C.), Vol. 34, No. 1, pp. 14-22, March 1959. HR Abstracts, June 1959.

One of the requisities in preparing pavement surfaces to study skidding in the laboratory is to subject them as nearly as possible, to the same kind of polishing action as they will get in actual pavement surfaces. In the NCSA Laboratory this is accomplished by the use of a circular track apparatus and the NCSA Wheel Slipperiness Testing Machine.

A resume of important conclusions reached from the test are:

Reducing the speed of vehicles from 60 to 50 mph is more effective as a safety measure than increasing the coefficient of friction from 0.4 to 0.6 and maintaining the speed of 60 mph.

The coefficient of friction in a locked wheel stop from 40 mph may be determined in the laboratory by using the NCSA test method. A coefficient of friction of 0.4 is equivalent to an angle of 69 deg in the NCSA wheel test.

Because tires on field skid test machines change due to rubber composition, tread pattern, and other variables, it would be desirable to calibrate all field equipment in terms of permanent, durable standards of pavement slipperiness. These could take the physical form of 3 in. by 4 in. glass plates having surfaces ground with carborundum of different degrees of fineness. Using the NCSA wheel or other small testing device suitable for both laboratory or field use the field machine readings can be expressed in terms of small permanent standards of slipperiness such as prepared glass plates. The ultimate description of road slipperiness should be in terms of these permanent standards.

If certain aggregates when used alone in an asphaltic concrete mix produce slippery pavements, the substitution of non-slippery fine aggregates for the slippery fines will effectively reduce the tendency of the resulting mix to become slippery.

The cure of slipperiness in pavements need not involve the total rejection of the slippery aggregate from use, but rather a substitution of a non-skid aggregate for a portion of the slippery aggregate.

(The present paper discusses the cure for slippery asphalt pavements but it is not intended to imply that slipperiness occurs only in this pavement type. The cure for slippery concrete pavements will be discussed in a subsequent issue of the Crushed Stone Journal).

44. Callahan, Joseph M. SKID BAR PIONEERED ON PLANES. Automotive News (965 E. Jefferson St., Detroit, Mich.), Vol. 33, No. 3692, p. 34, February 2, 1959. HR Abstracts, May 1959.

One of these days the auto industry is going to take a page out of the aircraft industry's book and make a major inprovement in the safety of car brakes.

This "page" could well be an anti-skid device which would permit maximum braking while preventing wheel lock and resultant skidding.

Dunlop Rubber Co., London, England, has marketed such a device for aircraft since 1952 and is now experimenting with a similar unit for autos.

The Dunlop unit is located on the brake at each wheel in such a way that it controls the effort applied by the driver and immediately relieves the brake pressure when an increase in wheel deceleration warns of impending wheel skid.

Of course, the big advantage in eliminating skidding is that the driver is able to maintain complete directional control of his car at all times.

Operation of this device is based on a small flywheel, driven from each wheel, which is decelerated by a spring during braking. If deceleration of the wheel is normal, the energy produced by the flywheel is not sufficient to collapse the spring and the unit remains inactive.

However, if ultra-rapid wheel deceleration occurs and skidding results, the flywheel will collapse the spring. Then, a small hydraulic valve relieves the brake pressure until the flywheel returns to its normal position as the wheel regains non-slip speed.

Thus far, Dunlop has conducted a comprehensive series of tests on a Jaguar Mark VII. The car has hydraulic disk brakes controlled by an anti-skid unit which contains some components from an aircraft-type unit.

The tests were made under rather extreme conditions, employing smooth, treadless tires running on a special skid track at the new British government-sponsored road research laboratory. Tests were made at all speeds up to 95 mph and were termed highly successful by the company. The test car was steered through a succession of obstacles under braking conditions which would normally result in the car being completely out of control.

A solenoid-operated valve was fitted to each anti-skid unit and the dashboard of the test car so that the units could be put out of action, permitting comparative tests of the anti-skid system and normal braking.

In one typical series of tests, the distance needed for braking the vehicle was reduced 23 percent when the anti-skid unit was operating. On these runs the car equipped with the bald tires was braked at 35 mph on a surface equivalent to ice.

Introduction of such an anti-skid unit is definitely some time away on U.S. cars because this system is only compatible with disk brakes and because a special full-power brake control valve would be required. This valve required a continuous supply of fluid to repressurize the brakes after the anti-skid unit has corrected a skid.. The master cylinder type of valve does not do this.

45. Zuk, William. THE DYNAMICS OF VEHICLE SKID DEVIATION AS CAUSED BY ROAD CONDITIONS (Presented at 1st International Skid Prevention Conference, University of Virginia, September 1958.) Virginia Council of Highway Investigation and Research, Virginia Department of Highways and University of Virginia, Charlottesville, Va., June 1958. 44 pp. HR Abstracts, February 1959.

A simple determination of the average coefficient of friction between vehicle tires and road surfaces is believed to be inadequate as a criterion for predicting the skidding accident potential of a road surface. Certain properties of a road such as non-uniform surface, crowns, superelevations, and curves may cause a skidding vehicle to deviate from its original path to such an extent that the vehicle skids out of the traffic lane into a ditch or oncoming traffic, or it may swerve, spin or tip over.

This study is limited to a consideration of the factors of skid deviation which are caused by road conditions. The dynamics of three basic cases are considered analytically, based upon Newton's laws of motion. Case (A) involves the study of skid deviation as caused by non-uniform surface, case (B) involves the study of skid deviation as caused by a transverse slope of road, and case (C) involves the study of skid deviation as caused by horizontal curves.

To substantiate the theoretical analysis, time-motion studies of an actual model vehicle skidding under several conditions are also presented.

Certain conclusions are drawn in connection with each case in an effort to offer additional criteria to aid in the determination of road surfaces which will be safe in emergency stops. Based on this theory and model study, it is suggested that field studies of actual in-service roads be made to determine the variation of surface coefficients of friction that does exist on a highway. Surfaces with too great a variation are potentially dangerous, and should be so treated.

46. ANTI-SKID. Think (International Business Machines Corp., 590 Madison Ave., New York 22, N.Y.), Vol. 24, No. 4, p. 27, April 1958. HR Abstracts, June 1958.

The driver of a stock model stepped on the accelerator and his car tore through a West Coast parking lot. Suddenly, he wrenched the steering wheel to the left and jammed on his brakes. Under normal conditions, the car would have been thrown into a skid, and probably would have turned over. But these weren't normal conditions, and the car didn't skid. At the wheel was E. Cooper Heard testing a device which he has invested--a stabilizer designed to control automobile skids and side-sway. It was being demonstrated for Safety Council officers and traffic police (80 percent of all traffic accidents occur as a result of skidding and resultant loss of control).

The device works on the gyroscope principle to combat and minimize skidding with forced balance. The device is a metal box 4½ in. square, 24 in. long, and weighs 62 lb. It clamps onto a car's rear bumper or may be bolted into the trunk or beneath the floor of the trunk. Inside the box is a very heavy, movable weight which acts against strong coil springs, according to the manufacturer, to counteract any tendency of the car's rear end to skid sideways on sudden turns. When the car begins to skid, the weight tends to remain right where it is--compressing one spring or the other and thus kicking the car's rear end right back where it was. The stabilizer also reduces vibrations which add to a car's wear and tear, and increases tire traction to provide up to 22 percent faster braking.

47. Sheehe, Gordon and Mercer, Samuel, Jr. LOCKED WHEEL SKID PERFORMANCE OF TIRES ON CLEAN DRY ROAD SURFACES. Michigan State University. Presented at the Highway Research Board meeting, January 1958.

Although engineering, legal, and educational groups are concerned with the skid performance of tires on dry roadways, most skid investigations have been conducted on wet surfaces. Because of the paucity of data, it was considered desirable to investigate the skid performance of several makes of tires on clean, dry, level road surfaces. Factors investigated included skidding velocity, tire make, wheel loading, and type of road surface. Data were obtained from trailer drag tests and panic stops of passenger vehicles. These data were used to determine the factors that influence the dry skid performance of tires and to determine the reliability of the square law formula for estimating the initial speed of a vehicle from the length of the skid marks laid down during a panic stop.

48. Skeels, P.C. MEASUREMENT OF PAVEMENT SKIDDING RESISTANCE BY MEANS OF A SIMPLE 2-WHEEL TRAILER. General Motors Proving Ground. Presented at the Highway Research Board meeting, January 1958.

There has been an increasing awareness of the seriousness of low friction wet pavements during the past several years. With the increase in interest, there have been developed numerous techniques for measuring the wet skid resistance. The increase in traffic volume on public highways has made it increasingly difficult to apply the simplest sliding brake stop techniques; on many of our most important highways, it is almost impossible to measure skid resistance by older methods because of the hazards involved and the interruptions of the flow of the traffic stream. This paper describes the design and construction of a simple 2-wheel trailer, using passenger car components readily available in any part of the country. This trailer can be towed in the traffic stream so that tests can be made in rapid succession without changing speed and without any interference with other vehicles.

This paper includes samples of data on numerous types of road surfaces.

49. Nagin, H. S. TECHNIQUES FOR APPLYING RESINOUS SKID-RESISTANT SURFACES TO HIGHWAYS. Reliance Steel Products Company. Presented at the Highway Research Board meeting, January 1958.

Continued development of resinous skid-resistant surfaces for highways by the Shell Chemical Corporation and Reliance Steel Products is reported.

A film is introduced which demonstrates the large-scale application of an epoxy resin non-skid protective wearing course on the Wyoming Avenue Bridge in Philadelphia, Pa. The method of cleaning and application is shown and a skid test of the new and old surfaces is demonstrated. A tensile test is shown illustrating the type of adhesion attained between this new resinous surface and concrete.

50. Stutzenburger, William and Havens, James H. POLISHING CHARACTERISTICS OF LIMESTONE AND SANDSTONE AGGREGATES IN REGARD TO PAVEMENT SLIPPERINESS. Highway Research Board Bulletin, No. 186, p. 58.

The coefficient of friction on dry highway surfaces regardless of stone composition and texture has in most cases been 0.6 or above. However, some of these same surfaces when lubricated by a small amount of water have given test results dangerously lower. Some theoretical aspects of this situation are presented along with results from a laboratory study of the fundamental factors affecting tractive friction.

A machine is described for measuring the coefficient of friction between the plane surfaces of 4-in. diameter stone specimens and a rubber annulus of slightly smaller diameter. Measurements were made both wet and dry on finely polished surfaces and on surfaces ground with 80 and 150 grit carborundum. Tests were conducted under varying loads and speeds. A 60-degree reflectometer was used to evaluate texture and roughness of the plane surfaces. Reflectivity (gloss) values correlated significantly with wet friction values in the highly polished ranges. Tests were conducted on representative samples of four limestones and two sandstones.

Coefficient of friction values of 0.01 and lower were measured on finely polished wet limestone surfaces. Sandstones subjected to the same polishing action averaged about 0.22 when wet. In another series of testing, the specimens were abraded with a coarse carborundum grit, and the wet friction values were consistently between 0.6 to 0.7 for both limestones and sandstones. For further comparison a piece of plate glass was abraded with this same material, and it too measured within the above limits. Dry friction values remained fairly constant regardless of type of stone or texture.

Test results reveal the tendency for fine grained particles bound in a matrix of similar hardness to polish more readily and to a greater extent than hard particles such as quartz bound in a soft matrix. Limestones, being typical of the former condition, polished easier than sandstones.

51. Whitehurst, E. A. and Goodwin, W. A. A DEVICE FOR DETERMINING RELATIVE POTENTIAL SLIPPERINESS OF PAVEMENT MIXTURES. Presented at the Highway Research Board meeting, January 1958.

As a result of a 5-year study of pavement slipperiness in Tennessee it was concluded that the type of aggregate used in the surface played a major role in determining the eventual slipperiness, or lack thereof. The results of this study have been previously reported. Present investigations are being made to determine what aggregates or combinations of aggregate may be used beneficially.

To minimize expensive and time-consuming field experiments, a device has been constructed to permit the testing of various surface mixtures in the laboratory. The device consists of an automobile wheel, driven by a variable speed motor, which spins against the test specimen. The specimen, either portland cement of asphaltic concrete, is 38 in. square and 6 in. thick. The speed of rotation of the wheel may be varied from below 10 to above 40 mph and the load of the wheel against the specimen may range from about 100 to 1,200 lb.

Tests may be made at one point on the specimen or the specimen may be moved in both directions while the wheel is spinning, thus producing a planning action across any desired portion of the specimen. A test on a single location usually requires from 30 min to 2 hr.

The measured parameter is the wattage required to drive the motor at the selected speed; as the pavement becomes slippery less power is required. A graph of wattage versus time is taken through use of a recording wattmeter, the relative decrease in power demand being indicative of the relative potential slipperiness of various mixtures. Typical power demand curves for several paving mixtures are presented.

52. Stables, E. R. THE SKID-WHEEL: NEW METHOD OF MOVING HEAVY LOADS ON SOFT GROUND. Engineering (35 Bedford St., Strand, London, W.C.2), Vol. 183, No. 4754, pp. 494-497, April 19, 1957. HR Abstracts, October 1957.

This article describes a projected method of moving heavy loads on soft ground. It records the origin, theoretical analysis, and development of a skid-wheel aircraft transporter up to the completion of a series of tests on a full-scale experimental model. The device may perhaps be of interest in fields of engineering other than the one in which it arose.

The "skid-wheel" (British Patent No. 759,608) as its name implies, is a cross between the skid and the wheel. Its purpose is to combine as far as possible the load-spreading ability, low height, and general simplicity of the skid with the low tractive resistance of the wheel. The idea arose from the problem of towing aircraft over natural soil; this problem has received considerable attention both in the United Kingdom and abroad, particularly because of the increase of tire pressures to well over 100 psi.

A summary of the main design features and the measurements made is given below:

Total load applied to the ground through two skid-wheels	4 to 8 tons (approx.)
Rim diameter of skid wheels	66 in.
Thickness	0.375 in.
Spherical radius	72 in
Angle of inclination of axles	18½ deg
Width of tracks made in the ground	14 in (4 tons) to 22 in. (8 tons)
Ground loading (at all imposed loads)	25 psi (Approx.)
Aircraft tire pressures	120/130 psi (approx.)
Depth of sinkage	0.4 to 0.9 in.
Distance from center of skid-wheel to center of contact area	22 in (mean)
Distance from center of skid-wheel to instantaneous center	25½ in. (mean)
Draw-bar pull (skid-wheels rotating)	200-600 lb per ton
Draw-bar pull (skid-wheels locked)	300-2,000 lb per ton

53. Giles, C. G. THE SKIDDING RESISTNNCE OF ROADS AND THE REQUIREMENTS OF MODERN TRAFFIC. Institution of Civil Engineers (Great George St., Westminster, London, S.W.1), Proc., Vol. 6, Road Paper No. 52, pp. 216-242, February 1957.

The paper deals with problems to be considered in ensuring that, in wet weather, the skidding resistance of roads is adequate for the demands of modern traffic.

Consideration is first given to standards required to meet the full performance of vehicles in braking, cornering, and acceleration, and the extent to which the requirements are modified by the manner in which vehicles are normally driven.

Methods of measuring skidding resistance of surfaces are briefly reviewed; the interpretation of test results is discussed from aspects of speed, tire-tread patterns, and seasonal variations.

Investigations on the relation between skidding resistance and the risk of skidding accidents are considered. The results show the skidding risks associated with different road characteristics.

Even the highest standards of resistance will not ensure complete freedom from skidding but the risk is greatly reduced with coefficients above 0.6; in most cases a value of about 0.5 is acceptable. As coefficients decrease below 0.4 the risk increases rapidly, but few present-day roads are in this range.

As a guide to meeting requirements a table of suggested sideway-force coefficients is given. The paper concludes by considering the main characteristics of surfaces which determine their resistance to skidding.

54. Giles, C. G. and Sabey, Barbara E. 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. HR Abstracts, May 1957.

In dealing with problems of skidding on wet and on icy roads, police reports of accidents can be of 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, representing 23 percent of the total number 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 reductions 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 invariably 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.

55. 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. HR Abstracts, Feb. 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 is reported. At each site studied the number of accidents generally will be small, so that the significance of the frequency with 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.

56. Giles, C. G. and Lander, F. T. W. 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?CCG.FTWL, April 1955. HR Abstracts, Feb. 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 single 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 mean 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.

57. Michael, H. L. and Grunau, D. L. DEVELOPMENT OF SKID TESTING IN INDIANA. Purdue University. Presented at the Highway Research Board meeting, Jan. 1955.

Many studies have been made in recent years with various types of skid equipment to evaluate skidding characteristics of pavement surfaces. This paper briefly summarizes the equipment used and the results found in these studies and presents a detailed description of a semi-automatic braking device used on a conventional automobile in Indiana.

The device is electrically operated and when activated applies the brakes and initiates measurement of stopping distance simultaneously. The speed at which the brakes were activated is also recorded. The method used eliminates much of the human variable from the measurement of stopping distance and made it possible for the good reproduction of stopping distance.

The skid testing program in Indiana is also outlined and preliminary results are presented. A number of experimental surfaces were tested along with four major surface types used in Indiana. These four were: Rock Asphalt, Portland Cement Concrete, Bituminous Concrete, and other Bituminous Surfaces. A total of 233 different roads were tested; each road being tested at three locations with two skids being performed at each location.

The skidding properties of the various roads were compared in terms of mean skid distances at 30 mph. Variability of the skid distances was determined along with the means.

The tests showed that Rock Asphalt had the best skidding properties of all the surfaces tested with respect to both average distance and variability.

Its means skid distance changed little between the wet and dry condition. Portland Cement Concrete surfaces provided relatively good skid characteristics but were subject to some polishing by traffic during the first few years of their life. The Bituminous Concrete surfaces tested had poorer skid characteristics than any other major type considered. The Bituminous Surfaces tested, other than Rock Asphalt and Bituminous Concrete, had a relatively low mean but were extremely variable. This variability was almost invariably associated with bleeding. Those roads with no bleeding yielded a mean 18 feet less than those that displayed some bleeding. The bituminous roads constructed with limestone aggregate had a lower mean than those containing gravel, although the limestone in some cases polished extensively under prolonged heavy traffic.

58. Nichols, F. P. THE PROBLEM OF PROVIDING SKID RESISTANT PAVEMENT IN VIRGINIA. Virginia Council of Highway Investigation and Research. Presented at the Highway Research Board meeting, January 1956.

This paper reviews briefly the previous 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 experimental 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 additional service life.

59. Whitehurst, E. A. and Goodwin, W. A. A STUDY OF PAVEMENT SLIPPERINESS IN TENNESSEE. Presented at the Highway Research Board meeting, January 1955.

This paper reports the results of a three-year study of pavement slipperiness in Tennessee. Throughout most of the study, slipperiness was measured through the use of a two-wheel trailer similar in many respects to those used by previous investigators. As a preliminary to the major investigation, comparisons were made of slipperiness of wet and dry pavements, clean and dirty pavements, and smooth and ribbed tread tires. In addition, the effect of load on the sliding wheel and of pavement and tire temperatures was investigated.

Toward the end of the study a number of pavements were tested for actual stopping distance with an automobile. A comparison of the two methods of test, trailer and automobile, is shown.

It is concluded that a major cause of pavement slipperiness in Tennessee is the susceptibility of certain limestone aggregates to polish under the action of traffic. It is also concluded that where such aggregates are used in portland cement concrete pavements, these pavements have the same potentiality for becoming slippery as do bituminous pavements containing the aggregates. It is appreciated that the polishing action will take a considerably longer time in the case of the concrete pavements than the bituminous ones. Within the limitations of the equipment employed, it is concluded that stopping-distance tests performed on a series of pavements will rate them with respect to slipperiness in essentially the same order as skid trailer tests, provided similar tires are employed and the test conditions standardized to the greatest possible degree.

60. Stegemann, W. and Bobeth, E. THE SIGNIFICANCE OF ADHESION IN RELATION TO THE PROBLEM OF SKIDDING AND TIRES AND DRIVING SAFETY. (In German) Road Abstracts (London), Vol. 21, No. 7, p. 100, July 1954. HR Abstracts, October 1954.

In Part 1 the author, in collaboration with K. Knauerhase, discusses the theoretical aspects of the skidding problem. It is stated that tires of synthetic rubber show a lower tendency to skid than tires of natural rubber, as the former are more readily wetted. The laboratory investigation of the adhesion of rubber and rubber mixtures is described. Reference is made to the effect of oil on roads in relation to the stability of vehicles. Basalt setts, which are particularly hydrophobic when coated with oil and therefore easily give rise to skidding, are discussed in some detail; remedial measures suggested include chemical treatment or burning. The importance of the wetting power of road surfaces and tires in relation to skidding is stressed.

In Part 2 the question of tire friction and its influence on driving is discussed. The effect of different road surfaces, moisture conditions and state of wear of tires is considered. A laboratory apparatus for the measurement of the friction coefficient for different states of tire wear and simulated road conditions is described. With this apparatus measurements are made of the displacement from the normal position which a freely suspended wheel undergoes under the influence of a given lateral force. Experimental results are depicted graphically. An analagous lorry-drawn apparatus for use on the road is described. The experiments are said to give a picture of the behavior of tires under the influence of centrifugal forces on curves and of lateral wind forces.

61. SKIDDING MACHINE AIDS RESEARCH ON TIRES FOR USE IN WINTER. USIS Chemistry Newsletter, Vol. VII, No. 2, p. 2, March 1953. HR 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. C. 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."

62. Gunsaulus. A. C. STOP THOSE SKIDS! SAE Journal, Vol. 61, No. 2, pp. 68-69, February, 1953. HR 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 antiskid 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 torque 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 proportional to its armature speed (24,3v, variation per 1000 armature rpm.) was chosen for the quick detection of the sudden changes in wheel 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 solenoid. 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 atmoshpere.

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, Pittsburgh, October 23, 1952. Paper available in full from SAE Special Publications Department. Price: 50 cents to nonmembers.

63. Giles, C. G. SKIDDING AND THE SLIPPERY ROAD. Paper No. 1152. Reprint from the Transactions of the Institution of Engineers and Shipbuilders in Scotland, pp. 195-252, 1952. HR Abstracts, July 1952.

This paper gives the results of investigations into the effect of vehicle, tire, and road-surface characteristics on skidding. Methods of measuring the friction between tire and road are described, and results obtained under different conditions are given. The results show big differences in the performance of wet roads and a desirable standard of performance is considered in the light of tests on accident sites and on some present-day roads.

The connection between types of road construction, road surface texture, tire-tread pattern, and skidding resistance on wet roads is discussed and suggestions are made as to the way motorists and others can help to eliminate skidding accidents.

64. ANTISKID DEVICES ON BICYCLE-TYPE BOMBER LANDING GEARS MAKE LANDINGS SAFER. Technical Data Digest, Vol. 16, No. 2, February, 1951. HR 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 Materiel 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 consist of a skid 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 to valve. When thus energized, the solenoid valve blocks the pressure from the pilot's metering valve to the brake and releases brake pressure. As the wheel regains speed, the detector unit senses this condition and de-energizes the solenoid valve, re-establishing 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 Decelostat 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 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.

65. Moody, R. D. EXPERIMENTS IN ASPHALT SURFACING FOR IMPROVEMENT OF NON-SKID QUALITIES. A.M.I.C.E., M.I. Mun. E., Deputy Borough Engineer, Stretford, England, The Surveyor and Municipal and County Engineer, Vol. CIX, No. 3031 Friday, March 10, 1950. HR Abstracts, May 1950.

Many miles of sett paving have been surfaced in Stretford in the last few years using precoated chippings as a wearing coat (British Standard Specifications 594, Part 2 (1945). A steady programme on heavily trafficked roads has enabled a comparison to be made of the wearing qualities from a non-skid angle and it is found that the surfaces are becoming smoother as time proceeds, the pre-coated chippings having apparently disappeared into the asphalt or having become covered by the fine asphalt. Skid tests show a progressive deterioration in the non-skid qualities, and the sideway force coefficient at 30 mph. of asphalt only three years old has fallen to 0.30 compared with 0.53 for asphalt laid a year ago.

With a view to obtaining a more permanent non-skid surface it was decided to lay a high stone content asphalt wearing course with no precoated chippings. Three lengths, each nearly a half a mile long, have been laid to slightly different specifications on the Trunk Road A. 56, which, in addition to a peak traffic of 1,400 vehicles per hour, carries a very heavy industrial traffic. Under these conditions the results should be of general interest.

The specifications and thicknesses used are tabulated below. The whole of the asphalt was machine laid. Binder course of varying thickness according to the shape of the old surface (including tram-lines) was laid over the whole area.

	Specification "A"	Specification "B"	Specification "C"
Stone content	55%	55%	60%
Soluble asphaltic bitumen	6.3-7.2%	6.3-7.2%	5.9-6.8%

Aggregate passing 200 mesh.	5.3-6.8%	5.3-6.8%	4.6-6.1%
Aggregate retained on 200 mesh, but passing 7 mesh.	31.0-33.4%	31.0-33.4%	27.1-29.5%
Grading of Stone			
Passing 1-in.	100%	100%	100%
Passing 3/4 in. . . .	100%	50%	100%
Passing ½-in.	50%	15%	50%
Passing ¼-in.	0.5%	0.5%	0.5%
Thickness to which laid	1½ in.	2 in.	1½ in.
Penetration of bitumen	50 at 25 deg. C	50 at 25 deg. C.	50 at 25 deg. C.

The first asphalt was mixed to Specification "A" and the surface obtained was most unsatisfactory. It was so poor that work was stopped pending an analysis of the troubles. The surface was very uneven in texture, some parts being very open and rough and others very smooth. This obtained in the same load of asphalt and sometimes the center of the run of the machine would be smooth and at other times the outsides of the run. There was also a considerable amount of dragging of the asphalt which necessitated feeding by hand to close the transverse cracks and voids before rolling.

It was obvious that part of the trouble lay in an uneven mix and it was decided in further work to increase the mixing time, which was eventually extended from the usual 2½ min. to 4 min. In the meantime, an analysis of the samples taken had been completed, and it was found that the stone had not been graded as ordered, there being too great a percentage passing ½ in. and ¼ in.

When the work was recommended, using the correct stone grading and a longer mix, there was a great improvement, but a slight variation in texture and dragging still persisted, despite the screed plate heater unit being used on the machine all the time, and various other experimental adjustments of the machine. This was finally cured by raising the temperature of the asphalt, but as the required temperature was found to be about 380 deg. F., which is excessive, the penetration of the bitumen was raised to 60/70, which permitted laying with very little dragging at 340 deg. F.

It was only with great reluctance that this change was made in the penetration of the bitumen, but it was necessary owing to the danger of the asphalt being brittle and thus causing cracking. It was unfortunate that the work was done during extremely cold weather, as with summer temperatures it is most probable that the asphalt with bitumen of 50 penetration could have been laid at lower temperatures.

The finished surface of the 55 and 60 percent stone content asphalt where the above precautions were taken is almost perfect, showing a uniform stone finish, but very dense throughout the full depth. It will be very interesting to observe how it wears and whether it maintains its non-skid value.

Commenting on the three sections generally, the Specification "C" with 60 percent stone content has given the most uniform texture in the surface and proved to be the easiest to lay.

66. Hoorneborg, J. C. SKID RESISTANCE ON NEW ASPHALTIC CONCRETE ROADS. Wegen, 1948, 22 (13/14), 138-40, July 1948. Road Abstracts, Vol. XVI, No. 3, March 1, 1949. HR Abstracts, June 1949.

On constructing new or reclaimed bituminous concrete roads the skid-resistance of the finished surface often appears to differ considerably. In the following lines an idea will be given of the influence of the air-temperature on the resistance attainable of a reclaimed asphaltic concrete surface, on the ground of recent experience, and results will be stated of a partly new method for the improvement of slippery surfaces.

It will be better not to apply sealing-coats on bituminous concrete surfaces as soon as the average day-temperature falls under 10 deg. C (50 deg F.).

When applying sealing-coats at an average day-temperature of 7 or 8 deg. C(45 or 46 deg. F.), surfaces are apt to become slippery or even very slippery.

In the cold months of the year it may be possible to roughen a slippery surface by a treatment with turpentine, combined with sandblasting. Such a treatment will raise the coefficient of resistance to about 0.55 or 0.60.

The expenses, this method entails, are rather high and vary between f 0.50 and f 0.55 (11 d. or one shilling) per m^2, or about 16 cents per sq. yd.

67. Schulze, K. H. and Hoffman, G. BEWERTUNG DER GRIFFIGKEIT VON FAHRBAHNMARKIERUNGEN. Strasse u Autobahn v 12 no 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 marking materials.

68. Gray, J. E. and Renninger, F. A. LIMESTONES WITH EXCELLENT NON-SKID PROPERTIES. Crushed Stone J v 35 n 4 Dec 1960 p 6-11, 15.

Various types of limestone defined; 5 specimens were tested by subjection to thousands of passes of rubber tires, increasing wear initially by spreading sand on surface; samples showed various degrees of slipperiness; extensive laboratory study of aggregates involved showed that some of the insoluble materials in stone and, to greater extent size of granules in insoluble material, promote skid resistance.

69. Peleg, M. ROAD FRICTION TESTS IN ISRAEL. Research Council of Israel--Bul v 8C n 3 Oct 1960 p 81-92.

Twenty-six points on main roads were examined with regard to their friction properties using Leroux "rugosimeter"; percentage of kinetic energy of pendulum absorbed by friction was determined; safety coefficient was calculated and allowable speed determined; it was found that, contrary to common view, cement concrete roads become slippery when wet and their safety coefficient in not high.

70. Wehner, B. GRIFFIGE STRASSENDECKEN. Bautechnik v 37 n 4 Apr 1960 p 135-42.

Gripping pavements; experiences with measurement of gripping capacity of roads; hysteresis losses; changes in gripping capacity due to seasonal and temperature conditions; comparison of different surface construction.

71. Normann, O. K. INFLUENCE OF ROAD SURFACES AND THEIR VARIABLES ON PASSENGER CAR SKIDDING. SAE--Paper n 205C for meeting June 5-10 1960 18 p.

Influencing factors are type of aggregate, cement or binder, age of surface, maintenance, foreign material on surface, and climatic effects; data showing variation in friction coefficients at various places on same surface in 108 tests conducted by towing 4-wheeled vehicle and measuring pull required and effect of speed on friction coefficients; polishing effect of aggregates; treatment of slippery pavements.

72. 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.

73. Maclean, D. J. and Shergold, F. A. POLISHING OF ROADSTONE IN RELATION TO RESISTANCE TO SKIDDING OF BITUMINOUS ROAD SURFACINGS. Great Britain, Sci & Indus Research Dept--Road Research Laboratory--Tech Paper n 43 1958 29 p.

Test method for investigating extent to which various types of roadstones will polish, factors causing polish, and relationship between polishing and resistance to skidding of road surfacing in which it is used; results indicate that on roads carrying less than 25,000 tons/day, rate of polish was related to traffic intensity and to features of road layout.

74. McLean, D. J. SELECTION OF ROADSTONES FOR RESISTANCE TO POLISHING. Surveyor v 118 n 3486 Feb 14 1959 p 149-50.

Development of laboratory testing apparatus to measure degree to which traffic can polish roadstones; polishing happened only when fine mineral powder was introduced between pneumatic tire and stone surface; laboratory tests were made with small specimens of various stones; road tests proved reliability of laboratory tests; role of skid resistance and heat; experimental results are given.

75. Gray, J. E. and Goldbeck, A. T. SKID PROOFING OF ASPHALTIC CONCRETE PAVEMENT SURFACES. Crushed Stone J v 34 n 1 Mar 1959 p 14-23.

Phenomena of kinetic energy, friction velocity and acceleration of gravity are discussed; National Crushed Stone Association's slipperiness testing wheel is described; series of laboratory tests for improving skid resistance of asphaltic concrete; reducing speed to 50 mph, special wet-weather restrictions, and use of non-slippery fine aggregates is recommended; establishment of permanent standards of slipeeriness.

76. DEVELOPMENT OF NEW NON-SKID ROAD SURFACE TREATMENT. Nat Research Council--Highway Research Board--Bul n 184 1958 16 p. Papers before Annual Meeting Jan 7-11, 1957.

Development of Resinous Skid-Resistant Surfaces for Highways, H. S. Nagin, T. G. Nock, C. V. Wittenwyler, 1-9; Application of New Non-Skid Surface Treatment on Connecticut State Highways, W. M. Creamer, R. E. Brown, 10-16, both papers describe use of Relcote, product based on thermosetting eposy resins and developed by Reliance Steel Products Co.

77. White, A. M. and Chambliss, J. W. MISSISSIPPI'S PAVEMENT SURFACE TESTING PROGRAM. Traffic Eng v 28 n 12 Dept 1958 p 24-5.

Analysis of series of tests to determine skid resistant properties of various pavement types; tests were based on Stopping Distance Method involving locking brakes of automobile moving at designated speed, measuring skidding distance, and calculating coefficient of friction; test results to be incorporated in future specifications for pavement surface design.

78. Pocock, J. D. and Bell, R. W. RESULTS OF SKID RESISTANCE TESTS IN WILTSHIRE. Surveyor v 117 n 3462 Aug 30 1958 p 867-9.

Tests conducted by Road Research Laboratory in southern England covered: eight types of aggregates, different surfaces, traffic density, age of surface and rainfall and humidity; locked wheel method and pendulum method used; results discussed and graphs given.

79. Goldbeck, A. T. THIS PROBLEM OF SKID RESISTANCE. Crushed Stone J v 33 n 1 Mar 1958 p 21-7.

Factors influencing skidding; slipperiness tests on road surfaces; concrete surfaces become polished by use; if improper mix was used in bituminous surfaces, asphalt may be squeezed out to road surface on hot days; role of locked wheels; better brake systems needed which keep rolling wheels on slippery surfaces; "sipe" in tires helpful; coat of asphalt-sand mixture used against slipperiness.

80. Giles, C. G. SKIDDING RESISTANCE OR ROADS AND REQUIREMENTS OF MODERN TRAFFIC. Instn Civ Engrs--Proc v 6 Feb 1957 p 216-42 (discussion) 243-8.

Standard required to meet full performance of vehicles in braking, cornering, and acceleration; extent to which requirements are modified by manner in which vehicles are normally driven; methods of measuring skidding resistance of surfaces; interpretation of test results from aspects of speed, tire tread patterns, and seasonal variations.

81. Siegel, S. T. SKIDDING IS OUR BUSINESS. Traffic Eng v 26 n 5 Feb 1956 p 200-2, 204-6.

Activities of Committee on Winter Driving Hazards; effect of temperature on slipperiness of icy surfaces; Clintonville tire tests; braking tests; traction tests; cornering and restrained cornering tests.

82. Giles, C. G. SKIDDING RESISTANCE OF ROADS. Surveyor v 115 n 3366 Oct 27 1956 p 842-3.

Consideration of how risk of skids is related to varying degrees of skidding resistance of surfaces in wet weather and to characteristics of different road

layouts and of vehicles; standards required to meet full performance of vehicles in braking, cornering and acceleration, and extent to which requirements are modified by manner in which vehicles are normally driven; methods of measuring skidding resistance of surfaces.

83. Grime, G. and Giles, C. G. SKID-RESISTING PROPERTIES OF ROADS AND TYRES. Instn Mech Engrs--Proc (Automobile Div) n 1 1954-55 p 19-30 (discussion), 45-56.

Importance of wet weather skidding in relation to road accidents; methods of measuring slipperiness of road surfaces; typical results for British roads; effect of such factors as types of surfacing and surface texture; how nonskid properties of tires depend on type of surfacing on which they are used, as well as on tread pattern.

84. SOLVING "SLIPPERY WHEN WET" ROAD PROBLEM. Pub Works v 85 n 10 Oct 1954 p 97, 106, 108.

Highway safety grain developed by Carborundum Co which improves skid resistance; fused alumina abrasive material of over 2000 hardness employed; successful tests in New York State reported; application methods.

85. Larson, C. E. DANGER--SLIPPERY WHEN WET. Eng News--Rec v 151 n 18 Oct 29 1953 p 45-6.

Concrete pavement of fine and coarse limestone aggregates results in surface which becomes highly polished; tar and slag chips can be applied to increase skid resistance; examples of slippery highways; it is asserted that slippery surfaces are also due to excess of asphalt; correction of slipperiness.

86. Giles, C. G. SKIDDING AND SLIPPERY ROAD. Instn Engrs & Shipbldrs in Scotland--Trans v 95 Part 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.

87. Richards, E. W. W. BITUMINOUS ROAD SURFACE PROPERTIES WITH SPECIAL REFERENCE TO SKIDDING. Roads & Road Construction v 30 n 358 Oct 1952 p 284-6.

Factors which make road surfaces skid resistant; tests on skid resistance of different dry and wet asphalt mix surfaces and asphalt seal coats.

88. SLIPPERY ROAD, CAUSE AND CURE. Commonwealth Engr v 39 n 11 June 1952 p 462-3.

Principal cause of slipperiness is excess bituminous binder; types of surface; methods of curing slipperiness.