In the second direction, accompanying this outdoor exposure, will be the standard laboratory tests on these same materials after they have been subjected to freezing and thawing, wetting and drying. Such laboratory work will, when compared to the outdoor experiment, tell us whether or not it is necessary to go through the actual construction of a test road in order to find out what may otherwise be predicted by the more simple and better controlled laboratory tests.

One attempt is to find stabilization with portland cement and also waterproofing with an additional admixture of bitumen, such as emulsified asphalt.

One outcome of this experiment might well be the choice of material for shoulders, or for bicycle paths. There has been some insistence on the part of planners that the highway is a transportation path for general traffic as well as for autos on the pavement. It is true, as Upham said, that the early engineers who located and designed highways carried over principles from the railroad field, and the foot passenger was left out of the design.

It is also expected that our laboratory research will investigate the effects of exposure on bitumens. Thin films of these bitumens will be exposed, for example, to ultra-violet light, which now seems to be the criterion of resistance of these bitumens.

Another useful field of investigation is a study of the testing process itself. At the present time, we have a number of tests for so-called stability, each one directed to find out the same property, as, for instance, the Hubbard-Field stability test, the ball test, the compression test, the Mini-track test, and the resistance of the materials to the forces which are generated either by the expansion of water into ice in freezing and thawing tests or the action of crystallization of materials like sodium sulphate. If it can be determined that one of these, the more simple test, will tell us what we want to know, there will be a great economy in laboratory operations.

In conclusion, I wish to express my appreciation of the helpful relations with, and cordial co-operation of, the Highway Commission and the Advisory Board. I desire to mention also the chairman of the former Highway Commission, Mr. James D. Adams, under whose responsibility this project was initiated.

DEVELOPING NON-SKID ROAD SURFACES

R. A. Moyer

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During the past five years, tests have been conducted by the Iowa Engineering Experiment Station under the writer's direction on more than 25 road surfaces of all types in Iowa, Indiana, and Ohio, under various surface conditions, as wet, dry, and snow- or ice- or mud-covered. In searching for a state in the midwest where a wide variety of surfaces and surface conditions, especially of the bituminous type, could be found, we selected Indiana as that state. Six different surfaces were tested in Indiana. They were: slippery asphalt macadam, excellent non-slippery rock asphalt, portland cement concrete, asphalt retread, road-oil mix, and bituminous mulch top, each providing varying degrees of skidding resistance. Since a large portion of our skid test work, and more recently studies of tire wear, gasoline consumption, and the total cost of motor vehicle operation, have been conducted in Indiana, it is indeed a pleasure to me to have the opportunity to report back to you concerning our findings.

Time will not permit including in this paper a report of the more recent work referred to above, relating to operating costs and the economics of highway improvements and highway transportation. However, a brief reference at your Road School to the results of these studies seems to me to be quite appropriate.

As engineers, we are frequently so engrossed in a mass of details related to the practical and technical phases of our work that we are likely to pay little attention to the broad economic problems involved in highway work. And yet our work as highway engineers has special economic significance in the choice of materials and methods of construction used, and the still greater economic significance related to the influence of such construction on motor-vehicle-operating costs. It was Wellington, the great railroad engineer, who, 50 years ago, defined an engineer as one who could do for one dollar what any bungler could do for two, if indeed he could do it at all.

With all the improvements in road construction and maintenance methods available to engineers today, the opportunities to lower construction costs, maintenance costs, and particularly motor-vehicle-operating costs, are greater than ever before. We have known for some time that car-operation costs were lower on paving than on gravel or natural earth roads. However, it was reassuring to find in our recent study of rural mail carrier car-operating costs in Iowa and Indiana that the difference in operating costs could easily be 2 cents per mile lower on paving than on earth roads. Now the average gas tax and license fee in Iowa and in Indiana is less than ½ cent per vehicle mile, and it is significant to note that this tax income, used for road construction and maintenance, is making possible a saving in operation costs 2 to 4 times as great. In the light of these figures, we have at least a partial measure of the good which can be accomplished in Indiana by its highway engineers and especially by the Purdue Road

School in stimulating the early adoption of the best methods of improving roads and in providing safe and economical highway transportation service.

ORIGIN OF SKID TESTS

Now coming back to the main subject of my paper, that of developing non-skid roads, you may be interested to know that tests to determine the slipperiness of road surfaces were conducted by the Iowa Engineering Experiment Station under the direction of Dean Agg as early as 1924. Since 1932, an intensive study of many phases of the problem has been conducted under the direction of the writer. As stated previously, road tests have been run on many surfaces and surface conditions, to determine the extent of the slippery condition, the probable causes, and the most satisfactory methods for correcting this condition. Accident statistics have been studied. The frictional requirements when braking and when driving on curves have been studied. The variable effects due to the condition of the tires, the load, the type of wheel suspension, and the speed of the car have also been studied. Interest on the part of engineers in developing non-skid road surfaces has been increasing steadily during recent years because (1) many serious accidents have been reported as definitely due to slippery road surfaces, (2) the demand for operating in safety at high speeds has stimulated the construction of non-skid surfaces, and (3) the development of many new types of surfaces, particularly of the bituminous types known to be slippery if not properly constructed, has also added to this interest. Nevertheless, since the majority of highway accidents are charged to the carelessness of the driver and so few to defects of the road, the real value of developing non-skid roads is not always appreciated by the public or even by all highway engineers. Just because cars do not always skid by sliding end for end or broadside over the road is no reason why such roads may not be considered as slippery. A non-skid surface will not only reduce the tendency to skid in this extreme way, but what is probably more important, but less evident, it will permit the driver to stop the car in far shorter stopping distances (Fig. 1), to make sharper turns, and to maneuver the car with a far greater margin of safety than on a slippery surface.

Statistics collected and published by the Travelers Insurance Company indicate that about 1,500 persons are killed annually, and 38,000 are injured in the United States in skidding accidents, and that an additional 6,000 are killed and more than 100,000 are injured in accidents in which the car is out of control, in many cases, no doubt, because the surface is slippery or at least not as non-skid as it might be. These data show quite definitely that slippery surfaces are the cause of many accidents; and, since we also know that this

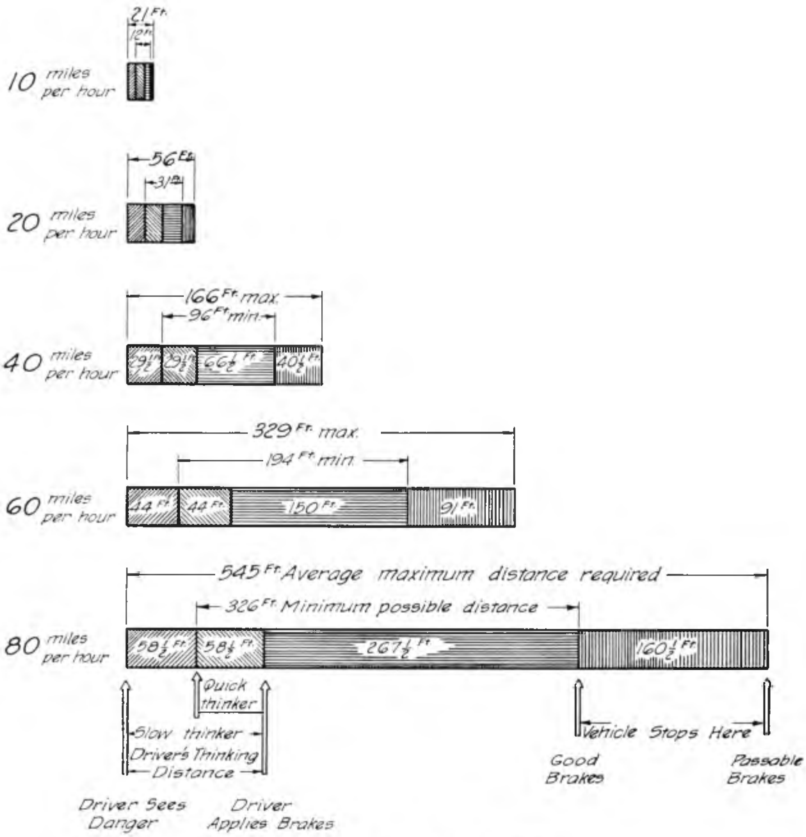

Fig. 1. STOPPING DISTANCES

Safe speeds should provide for a factor of safety in stopping and should be based on the average maximum stopping distance required and not on the minimum possible distance. (Arrangement adopted from Public Safety, July, 1935)

slippery condition is the result of improper construction and maintenance, we would like to call to the engineer's attention his obligation to correct the slippery condition as soon as possible.

METHODS OF CONDUCTING TESTS

Before presenting some of the more important details concerning the design features and corrective measures to be adopted to build skid resistance into the more common surfaces of today, a brief discussion of the methods of conducting the road tests, and some general observations made by the writer in connection with these tests may be helpful in obtaining a clearer understanding of the problem.

Tests were conducted using a two-wheel trailer test unit (Fig. 2) equipped with either new tread or smooth tread tires and an integrating dynamometer specially designed to measure the skidding forces. Since the wet condition creates the most common hazardous condition, a water tank was placed on the tow truck to sprinkle the road when running the wet tests.

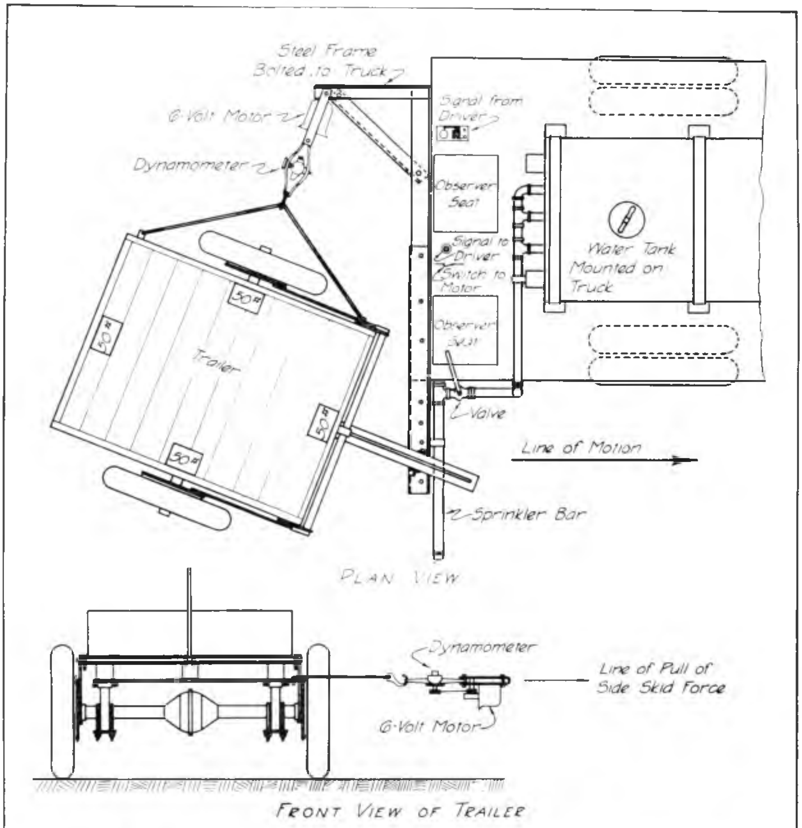

Fig. 2. Arrangement of test equipment used for determining the coefficient of friction of tires on road surfaces when skidding sideways.

The resistance to skidding that a given surface can provide is best expressed in terms of the coefficient of friction, which is the ratio of the force causing the tires to skid to the load on the tires. If a large force is required to cause skidding, the coefficient is large; if the force is small, the coefficient is small. The tests indicated that practically all roads in the dry condition can provide friction with a liberal amount to spare for the ordinary driving demands and even for the demands when an emergency arises. Many surfaces in the wet condition were found to be almost as safe as in the dry condition, but the tests indicated that there are many surfaces which are dangerously slippery when wet. The surfaces which were found to be most slippery when wet were the bituminous types glazed with a coating of surplus oil, asphalt, or tar. Surfaces covered with snow, ice, or mud were also found to be very slippery. The latter is not a characteristic of the road surface, but a condition which must be corrected by proper maintenance, as will be shown later.

EFFECT OF SPEED ON SKIDDING

In the early work on skidding, tests were conducted at low rates of speed at which the large uniform tractive forces required of the towing vehicle could easily be provided. In the more recent work, the variable effect due to speeds ranging from 3 to 40 miles an hour was investigated. In certain respects, the results were almost startling, because they indicated for the first time how slippery certain surfaces or surface conditions really are. On certain surfaces in the wet condition, it was found that at 40 miles an hour the friction available was only one fourth to one fifth as great as at 10 miles an hour (Fig. 3). In fact, under certain conditions, these surfaces were found to be equally as slippery as snow- or ice-covered surfaces. As was previously stated, the frictional resistance which can be developed by a rubber tire on a dry, hard, and firm surface is considerably greater than is required for ordinary or even for emergency driving operations. It is the wet condition, or the presence of excess oil, mud, snow, ice, or of loose sand or gravel or of wet leaves on the surface, which makes the road slippery. The wet condition is the most common cause of slipperiness, and provides surfaces with the widest range in frictional resistance, hence, the greatest uncertainty to the driver in regard to what he may expect with surfaces in this condition.

In theory and as evidenced by our tests, the total frictional resistance to skidding is equal to the true frictional resistance between the two surfaces, plus the resistance which results from a mechanical interlocking of the tire tread with the road surface. This mechanical resistance is brought about by the minute particles of rubber interlocking with equally small projections in the road surface which cause the rubber to shear off as the tire slides over the surface, in extreme cases leaving the debris of rubber in its path, commonly known as the skid marks. The true frictional resistance is theoretically proportional to the normal load supported by the tire. The mechanical resistance, however, is dependent not only on the normal force or load on the tire, but also on the area of contact of the tire with the road surface. Surfaces which are smooth, which provide a large contact area for the tire and

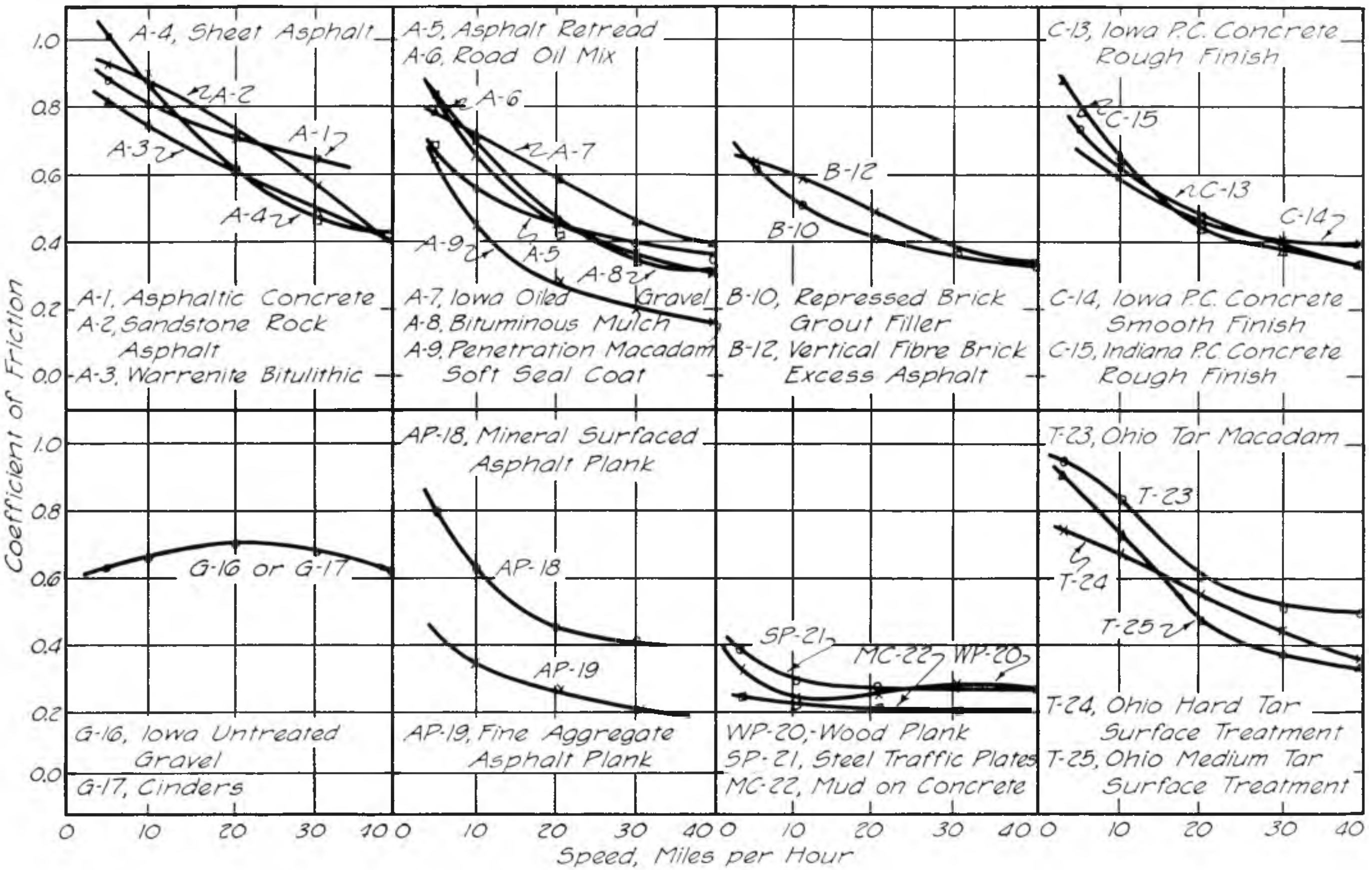

Fig. 3. Coefficients of friction for smooth-tread tires skidding straight ahead on wet surfaces.

close and intimate contact, should, as indicated by our tests, provide the greatest frictional resistance against skidding. Conversely, surfaces which have a rough knobby surface texture do not provide the intimate contact and therefore do not furnish the equally large frictional resistance provided by smooth surfaces with a gritty finish.

EFFECTS OF WET SURFACES

On wet surfaces, the water serves as a lubricant, unless it can be squeezed or squeegeed from the surface as the tire rolls over it. This squeezing and squeegee action is very effectively carried out at slow speeds even when "bald-headed" or smooth-tread tires are used. At speeds above 20 or 30 miles an hour, the tires fairly skim over the surface, and it is far more difficult to remove the excess water and to eliminate the lubricating effect of the water. If the water is trapped between the tire and the road, skidding resistance drops off sharply. On wet surfaces it is important to recognize that a large area of intimate contact is necessary to develop high frictional resistance; that small grooves must be provided in the road and in the tire to permit the excess water to escape; and that the aggregate on the surface must be hard and sharp with many small points of contact to grip the tire and prevent skidding. Tests conducted by the writer indicated that surfaces with a sand-paper-like finish provided greater frictional resistance when wet than surfaces on which large-sized aggregate was used to develop a rough-knobby finish. Surfaces with a hard silica sand, quartzite, trap, or similar hard aggregate were more satisfactory than surfaces on which soft limestone or other soft, highly absorptive aggregate was used. It did not seem possible to squeeze out the water as effectively on surfaces on which soft and highly absorptive aggregate was used as when hard impervious aggregate was used. Furthermore, it may also be said that to reduce slipperiness for any purpose, hard abrasive material, such as carborundum or a sharp sand, generally will be more effective than a soft limestone, shale, or the like.

Another important characteristic of surfaces revealed by the tests was that surfaces which were highly polished or glazed were quite certain to be dangerously slippery when wet. Presumably on a highly polished or glazed surface, such as on a smooth steel plate, a steel troweled or highly polished concrete surface, or a glazed-over asphalt surface, the water is trapped between the tire and the road surface and cannot be squeezed out as effectively as on a somewhat rougher textured surface which has the sand-paper-like or gritty surface finish.

In view of these general observations concerning the skidding properties of road surfaces, let us now examine the more important surfaces in general use today, such as portland cement concrete, the bituminous types, asphalt plank, brick, steel traffic plates, wood plank, untreated gravel, mud-, snow-, and ice-covered surfaces, and snow- and ice-covered surfaces treated with cinders.

PORTLAND CEMENT CONCRETE SURFACES

The portland cement concrete surfaces provide the largest mileage of a uniform standard of construction among all the high-type surfaces used in this country today. The skidding properties of portland cement concrete were found to be the most consistent of all the surfaces on which tests were run. While the skidding resistance was not as high on the wet portland cement concrete as on certain bituminous types, the driver has the assurance of moderately high resistance to skidding, and he knows by experience just about how much he can depend on the wet portland cement concrete to protect him. In recent years the demands for greater frictional resistance required at the higher speeds make it desirable to build the greatest possible skid-resistance into all surfaces. In portland cement concrete surfaces, this may be accomplished by brooming the surface or by finishing it with a canvas belt.

A recent survey has shown that more than one half of the state highway departments and many city departments now specify brooming for the final finish on portland cement concrete pavements. The brooming or belting operation should bring the sharp sand grains to the surface and should remove or break up the coating of cement paste which is responsible for the slippery condition that is certain to develop on portland cement concrete surfaces finished with a steel trowel. The cement paste develops a hard-surface finish which is polished smooth by the wearing action of traffic. Such a surface absorbs water easily and it does not appear possible to squeeze out the excess water readily, nor does it have the grittiness of concrete surfaces finished with a broom. The use of a liberal amount of clean, sharp, hard sand in the mix, even leaning toward an over-sanded mix, should improve the skid resistance of portland cement concrete. Excessive manipulation, vibration, or finishing draws an excess of cement paste to the surface and is certain to contribute to the slipperiness of surfaces so constructed. Portland cement concrete surfaces rarely become dangerously slippery when wet. However, if they do, the most effective treatment is to cover such surfaces with a bituminous mat one inch to two inches thick, of a type known to have a high-skid resistance as will be described later.

The wear on a high-quality portland cement concrete surface caused by traffic is very small; and since the hydrated cement paste has a hardness or wearing resistance approaching that of the aggregate, concrete surfaces are likely to lose some of their grittiness with age. Proper brooming will prolong the high-skid resistance present on the new concrete surfaces. The application on the surface of the green concrete of corundum, carborundum, or emery recrush or gannister or similar abrasives which are considerably harder and more wear resisting than the cement or aggregate, provides a method of treatment which is known to be very effective on concrete stairways and offers a possibility in building a more permanent skid-resistance into our portland cement concrete roadways.

BITUMINOUS SURFACES

Tests on bituminous road surfaces provided the largest variation in frictional resistance found on any of the surfaces tested. These surfaces, popularly known as "black-top," are generally thought of as dangerously slippery when wet. The results of skid tests on several bituminous surfaces substantiated this belief. However, the tests on the majority of bituminous surfaces in the wet condition provided frictional resistance appreciably higher than that obtained on any other type of surface tested. It can now be said without fear of contradiction that it is possible to build "black-top" surfaces which are as free from the dangers of skidding as any road surface in common use today. Furthermore, with the information now at hand, there is no reason why every mile of bituminous road cannot be made reasonably safe from the hazards of skidding.

An examination of the bituminous surfaces found to be slippery revealed that they were covered with heavy seal coats of an excess of bituminous material. The surfaces which offered high resistance to skidding were covered with sharp, hard sand, or with hard and finely crushed rock particles, held in place by the weaker bituminous cement (Fig. 4). As the tops of the sand or rock particles were uncoated with bitumen, these surfaces may be said to have a sand-paper-like finish, renewable under the action of traffic and weathering. It should be recognized that excess tar or asphalt in a bituminous mixture is not only certain to cause a slippery surface in hot weather, but is also likely to cause the surface to be unstable and to creep or shove and to form ruts under the action of traffic. The use of certain emulsions or cut-backs of the slow-, medium-, or rapid-curing type appear to cover the aggregate in thinner and stronger films than if straight oil asphalts or asphalt cements are used. These thin films wear off faster, especially on hard non-absorptive aggregate, than the thicker films obtained in the use of the heavier oil asphalts, and, therefore, emulsions and cut-backs can be expected to develop a higher skid-resistance than oil asphalts and asphalt cements.

Various trips by the writer during the past two years, covering about 6,000 miles of bituminous surfaces in both the eastern and western states, revealed that the application of a plain seal coat on some of the bituminous surfaces was the most common cause of the slippery condition observed on possibly 1,000 miles of road, and that the surfaces which

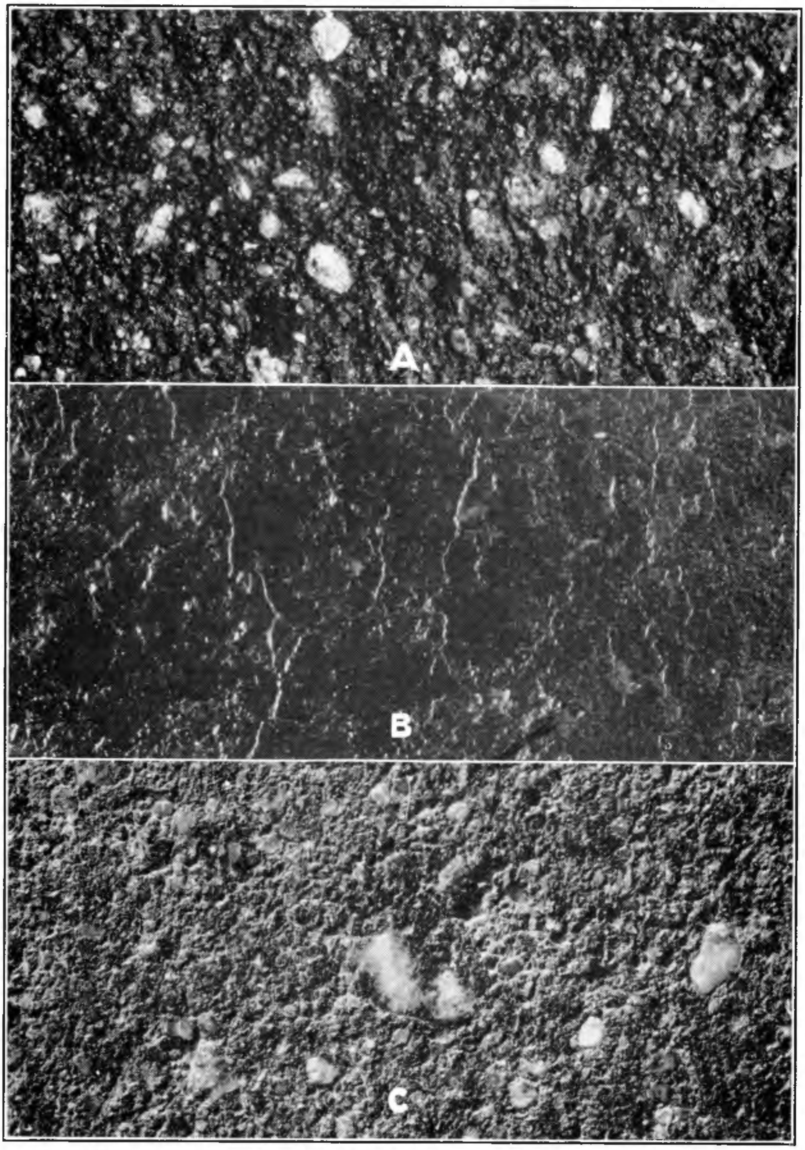

Fig. 4. Microphotograph of "black-top" road surfaces: (a) asphaltic concrete with sheet asphalt top, A-3, showing typical sandpaper texture; (b) oiled gravel, A-7, showing glazed condition due to excess asphalt; (c) oiled gravel, A-7, showing exposed aggregate on typical surface.

appeared to be non-skid were constructed without seal coats or with seal coats liberally covered with sand or crushed rock chips and clean screenings. The use of a dense graded mix or of fine graded aggregate for cover material seemed to provide the water-tightness which is necessary in regions where freezing and thawing may cause disintegration of surfaces not so protected. Where seal coats are used to provide a water-tight, non-skid, wear-resistant surface, a recent survey made by the writer revealed that the application of 0.2 gal. per sq. yd. of a cut-back asphalt or a quick-setting emulsion was immediately followed by spreading 35 lbs. per sq. yd. of aggregate 3/8-inch to 40-mesh size with a mechanical spreader. The aggregate was brushed evenly over the surface and rolled with a 3-wheel, 10-ton roller. In the city of St. Louis, 1,800,000 square yards of anti-skid surfacing have been placed. A large part of this work was done at intersections and at each approach 150 feet back from the intersection. The Director of Streets, Mr. McDevitt, reports that accidents at intersections so treated have been reduced approximately 50 per cent.

Bituminous surfaces which are glazed over with excess asphalt and which are known to be slippery may be improved by scarifying the surface and by applying sand or screenings or rock chips uniformly over the surface which is heated either by the sun or by a heater, honing or planing it with a blade, and finally rolling the surface with a moderately heavy roller. Another possibility is that of cutting back the excess asphalt with a volatile solvent such as kerosene or a fuel-oil distillate, then applying gritty cover material to blot up the excess binder and again rolling it. While limestone dust and powdered asphalt are very effective in drying an oily surface or in blotting up the excess asphalt and in stabilizing the surface, they lack the grittiness which sand or the coarser screenings and rock chips can give the surface to make it highly skid-

Fig. 5. General view (1936) of penetration macadam, A-5 type (see Fig. 3), on Indiana State Road 29 between Deer Creek and Burlington. A penetration macadam surface treated in 1934 with a seal coat and an excess of cover stone 1/4- to 3/4-inch size, providing a rough open-textured type of surface. The cover stone was a fairly soft limestone with no oil showing on the exposed side. The sharp edges were worn smooth at the time of test. The surface was smooth riding, but the rough open texture caused a rumbling noise typical of this type of treatment.

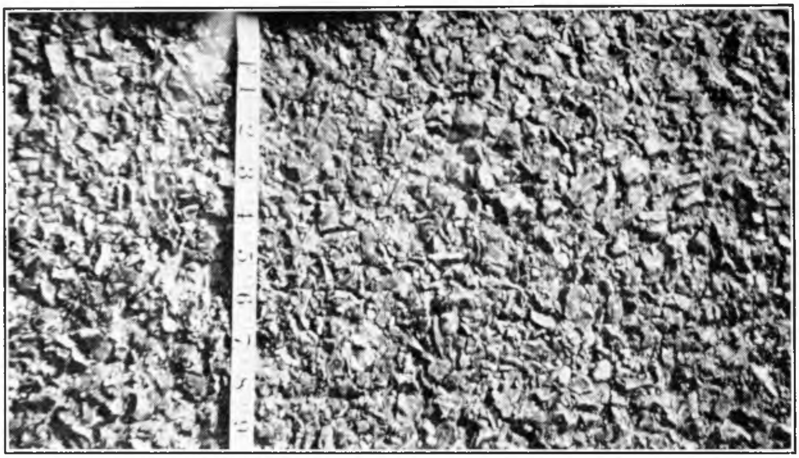

Fig. 6. Surface texture of penetration macadam, A-5 type, as shown in Fig. 5.

Fig. 7. General view (1936) of sandstone rock asphalt, A-2 type (see Fig. 3), on Indiana State Road 29 between Burlington and intersection with State Road 28. Rock asphalt surface treatment placed on an old penetration macadam in heated condition in June, 1936. The surface was smooth and had a typical "sandpaper" finish similar to the rock asphalt surface tested in the 1933 skid tests.

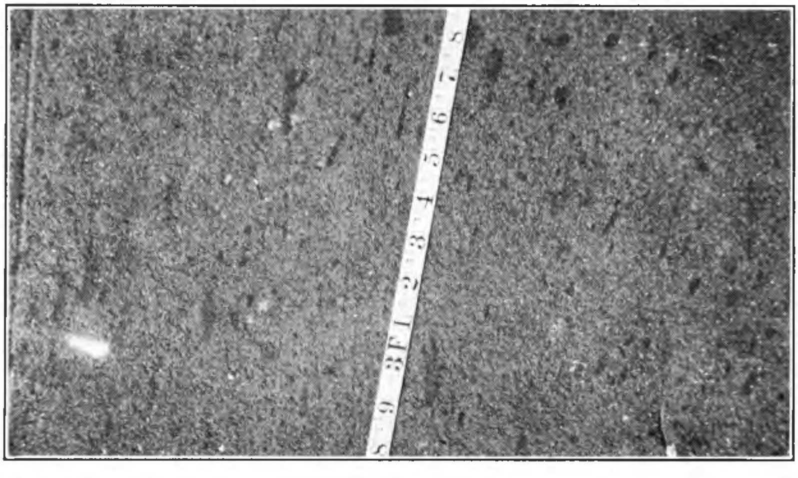

Fig. 8. Surface texture of sandstone rock asphalt, type A-2, as shown in Fig. 7.

resistant. The limestone screenings, or rock dust, or powdered asphalt should only be used in combination with the abrasive aggregate required to make the surface non-skid. If a large excess of asphalt is present, greater effort is necessary to blot up this excess by using rock dust and powdered asphalt. As stated previously, the use of large stones will develop a surface with a rough-knobby finish (Figs. 5 and 6) which, on a glazed asphalt, is not as permanent and as satisfactory as the treatment providing a gritty sand-paper finish (Figs. 7 and 8).

MISCELLANEOUS TYPES

Certain surfaces, such as wood plank, smooth steel traffic plates, and ordinary asphalt plank, were found by test to be as slippery when wet as icy surfaces. These materials are generally used on bridge floors, where skidding accidents are far more dangerous because of the restricted roadway. They are so slippery that they should not be used under any conditions on our highways unless they are provided with some type of gritty surface finish. The wood plank may be covered with a bituminous treatment and suitable sand or stone cover material. The steel traffic plates should have a stud or grid design providing sharp edges which will grip the tire and prevent skidding. The surface of the ordinary asphalt plank should be covered with sharp, gritty aggregate which may be rolled or pressed into the plank to form a rough-textured gritty finish.

BRICK SURFACES

Brick surfaces which are free from excess filler were found to have skidding resistance slightly lower than that obtained on the portland cement concrete surfaces. However, brick surfaces with excess filler which extrudes or bleeds out of the joints covering the greater part of the surface with asphalt were found to be as slippery as bituminous surfaces with heavy seal coats of excess bituminous material. This is only natural because the cause of the slipperiness is the same in both cases—the excess bituminous material on the surface. Recent developments in the manufacture of brick pavers and in brick pavement construction have greatly improved the skid-resistant properties of brick pavements. De-aired, vertical fiber brick with lugs should provide a wear-resisting, gritty surface finish. When there is any difficulty in obtaining the gritty finish, it is possible to face the surface of the brick with corundum, carborundum, or emery grits during manufacture and thereby provide a permanent wear-resisting and skid-resisting surface which is the equal of any road-surfacing material now in general use.

Bleeding at the joints has been practically eliminated by using a blended asphaltic joint filler mixed with a mineral flour to provide a stable mix with a low coefficient of expansion. Also, before applying the joint filler, the brick surface is sprayed with a calcium chloride solution composed of 35 per cent calcium chloride, 1 per cent starch, and 64 per cent water. By this method, the surplus asphalt may be scraped and peeled off the surface after it has cooled and hardened, leaving a clean surface with flush-filled joints. Brick surfaces with excess asphalt may be treated with sand or similar gritty cover material to blot up the extra asphalt, using a method similar to that described in connection with the treatment of slippery bituminous surfaces. Traffic will eventually wear off the excess asphalt and expose the clean brick, but skid-proofing the surface will hasten this process and will provide a high resistance to skidding in the meantime.

UNSTABILIZED SURFACES

Sand, gravel, cinders, or macadam surfaces can provide a uniformly high resistance to skidding in the wet or dry condition, provided the surface is firm and reasonably free from loose material. Loose aggregates, especially sand and gravel pebbles, act as ball bearings under the tires, causing variations in the skidding resistance which make it difficult to steer, and are, therefore, responsible for many accidents. These surfaces should be stabilized with clay or oil or with a similar type of binder which will prevent the loose condition. The loose condition creates another serious hazard — the dust hazard which interferes with visibility. It also increases the cost of transportation in the form of increased fuel, tire, car repair costs, and road maintenance costs to more than justify the cost of stabilizing the surface. Engineers and road officials should realize that untreated surfaces are expensive and dangerous, and take much of the pleasure out of driving for the present-day motorist.

ICE SURFACES

The results of tests on mud-, snow-, and ice-covered surfaces clearly indicated that they constitute the most uniformly hazardous road conditions which the motorist is likely to encounter. Ice and sleet were found to be particularly slippery, providing a frictional resistance only about one tenth as great as that provided by a dry concrete surface. A driver venturing out on a freshly formed icy surface with a car not equipped with tire chains is inviting all kinds of trouble. The crown of the average city street introduces enough slope to cause the car to slide into the curb unless the driver can straddle the crown line. The car cannot climb a long grade steeper than 3 or 4 per cent, and will be very likely to slide down, completely out of control, on grades steeper than 5 per cent. The seriousness of the snow and ice problems as related to skidding is indicated by the fact that about 80 per cent of all skidding accidents in Iowa, for example, were found to occur in the four winter months. The correction of this slippery condition is clearly a maintenance problem and demands prompt attention, if it is to be effective.

Ice forms at temperatures close to the freezing temperature, and if sand or cinders are applied on the surface promptly at this time, the sand and cinders will be imbedded in the ice, thereby raising its frictional resistance to 3 or 4 times that which it can provide without such treatment. If the application of the sand or cinders is postponed until much lower temperatures prevail, the sand or cinders will not be imbedded into the ice, and the wind and traffic will whip them off the road. If the stock piles of sand or cinders are treated with a solution of calcium chloride, using 50 pounds of calcium chloride per cubic yard of sand or cinders, imbedding of the sand or cinders so treated may be accomplished at temperatures considerably below freezing.

In certain states in this country, notably in Michigan, calcium chloride and sodium chloride have been applied directly on the icy surfaces. It has been found that such treatment of ice on portland cement concrete surfaces causes serious damage to the concrete in the form of scaling and a gradual disintegration of the concrete. For this reason the Portland Cement Association advises against the use of sodium or calcium chloride and recommends that the sand or cinders be heated before they are applied on ice-covered concrete road surfaces. During the past year the Iowa Highway Commission maintenance forces effectively removed ice from concrete pavements in strips about one foot in width by scraping the ice from the pavement, using heavy road scrapers to which short stout blades were fastened, projecting slightly below the standard blade. By exposing two such strips of ice-free surface in each traffic lane, the safety of travel was greatly improved.

SNOW SURFACES

Snow, especially dry snow, has two to three times the skid-resistance obtainable on ice. However, the transition from snow to ice may be made so easily that the driver has no assurance that the snowy surface is free from ice. For this reason, maintenance men should lose no time in removing the snow from the pavement or in applying sand and cinders at all intersections, on hills, and on curves as soon as the snow becomes packed. Traffic will assist in the imbedding process and, if the temperature is close to the freezing point when the snow is likely to change to ice in the traffic lanes, the prompt application of sand or cinders before this transition takes place will make imbedding into the surface more satisfactory. Black cinders are imbedded more readily when the sun shines than the lighter colored sand because the cinders absorb the heat of the sun. Scraping the dry, packed, frozen snow from the pavement is frequently possible and this is a very effective treatment. With the increased travel during the winter and the increased demand for all-weather highway transportation service which is evident today, maintenance engineers must plan to act promptly to meet the emergency slippery road conditions created by ice and snow, if skidding accidents from this source are to be eliminated.

MUD ON ROAD SURFACES

A skidding menace which is the cause of many accidents on rural pavements is the presence of mud on pavements. The mud is either splashed on to the pavement from the shoulder when a car runs into the rut which frequently forms adjacent to the pavement, or when the car runs out on the shoulder, or it is tracked on to the pavement from muddy side roads, farm drives, or field entrances. On important roads, the writer recommends that the shoulders of these roads be surfaced with gravel, cinders or crushed rock for a width of 8 or 10 feet. Not only would the mud hazard be eliminated in this way, but shoulders could then be used to good advantage as traffic lanes when ice or sleet is forming on the pavement. The tracking of mud on to the road at intersections can be prevented by surfacing all these approaches with gravel, sand, or crushed stone for a distance of 50 or more feet from the pavement.

In a recent questionnaire sent out by the writer for the Safe Roadways Committee of the American Road Builders' Association to all state highway departments and 90 city street departments, one of the questions called for a statement in regard to the mileage of roads and streets under their jurisdiction which each department considered to be safe from the hazard of skidding. The answers to this question were generally indefinite, because the engineers had no factual basis for giving a definite answer. The only way by which the slipperiness of a road surface can be definitely determined is by an actual road test at various speeds using equipment of the general type used in our studies. In the cities of New York and in St. Louis, such equipment has been built and tests are proposed on the various surfaces in these cities, starting this spring. The writer recommends that state highway departments and city street departments conduct tests along these lines and eliminate the surfaces which the tests indicate to be slippery.

CONCLUSIONS

In this report, the writer has attempted to explain why road surfaces are slippery and has suggested remedies for correcting this condition. In our driving tests on curves, in the braking tests, and in our observations of traffic, we have found that the margin of safety when driving at the high speeds of traffic today is small, even on dry surfaces where high coefficients are available. Accordingly, the engineer should make every effort to build the maximum possible amount of skid-resistance into all road surfaces. He should not build surfaces with, or permit surfaces to develop, a polished or glazed condition. He should make every effort to maintain a surface with a "sand-paper" finish, or with a smooth, gritty finish in which hard abrasive aggregate is securely held in place by a somewhat softer cementing medium (Fig. 9). The ideal skid-resistant surface is one in which this gritty surface condition is continually renewable under the action of traffic. With our present knowledge of the causes of slippery surfaces and the remedies to prevent slipperiness, construction and maintenance departments should now be able to develop construction and maintenance standards which will insure that every mile of road is skid-resistant. When this is brought about, "slippery when wet" signs will disappear from our streets and highways and another milestone in traffic safety will have been passed.

Fig. 9. A typical non-skid surface as developed by the California State Highway Department. Hot 94 + road oil covered with ½-inch to ⅛ inch screenings. The use of screenings of this size makes an effective non-skid cover which will not be kicked out readily by traffic.

DEVELOPING NON-SKID ROAD SURFACES

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I consider Professor R. A. Moyer's report, published in the December, 1933, *Proceedings of the Highway Research Board of the National Research Council,* entitled, "Skidding Characteristics of Road Surfaces," as one of the greatest contributing factors to the solution of the highway safety problem.

This subject naturally has for its background safer highways, as otherwise there would be no point in its discussion. It is true that many things contribute to accidents. Unless we attack all the causes, little progress will be made in solving the problem. Causes vary in degree. Some are difficult to solve,