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16. ABSTRACT

All too often we read of an accident being caused by an automobile skidding out of control on wet pavement. Many factors, including driver error and mechanical limitations of the vehicle, can contribute to this type of accident, and we are inclined to place the blame primarily in this personal area. However, the engineering profession must be sure that all items within its control are not contributing to the problem.

Within highway engineering, considerable emphasis has been given in the past to geometrics, with the expectation that the natural character of the pavement materials would render them "skid proof." We now find this not to be always true, so we must give special consideration to the characteristics of the pavement surface. This involves either building pavements with durable skid resistant surfaces, or applying surface treatments to existing pavements to improve their skid resistance.

Several highway agencies throughout the world have been engaged in skid resistance research for several years. This article discusses the findings in regard to the construction of high initial skid resistant pavements, and the restoration of existing pavements to satisfactory skid resistance levels, with special emphasis on experience in California. However, before discussing ways to improve pavement surface characteristics, it is necessary to explain what is meant by the term slippery pavement and what properties characterize the frictional performance of pavements.

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Tire Skidding Characteristics
Grooving
Hydroplaning
Skid Resistance Testing

SKIDDING ON HIGHWAYS, PREVENTIVE AND CURATIVE MEASURES

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All too often we read of an accident being caused by an automobile skidding out of control on wet pavement. Many factors, including driver error and mechanical limitations of the vehicle, can contribute to this type of accident, and we are inclined to place the blame primarily in this personal area. However, the engineering profession must be sure that all items within its control are not contributing to the problem.

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of existing pavements to satisfactory skid resistance levels, with special emphasis on experience in California. However, before discussing ways to improve pavement surface characteristics, it is necessary to explain what is meant by the term slippery pavement and what properties characterize the frictional performance of pavements.

The Slippery Pavement

A slippery pavement has been defined as one which lacks adequate skid resistance for maintaining proper vehicle control during wet pavement maneuvers, presuming the vehicle and its tires are in proper condition. This loss of control is due to a loss of traction or inadequate tire-pavement friction. This article deals with this type slipperiness and not that condition created by a coating of snow or ice.

The contact area of a tire rolling or sliding on a wet surface is hypothesized as being composed of three distinct zones. The forward contact area where the tire first contacts the water film is Zone 1. In this area the tire is actually floating on a film of water. This film thickness progressively decreases from forward to back as the individual tread elements traverse the surface and the tread elements attempt to squeeze out the water between the rubber and the pavement. Next is Zone 2, which is the transition or draping area. In this area the tire elements penetrate the water film and begin to drape over the major asperities and make contact with the lesser asperities of the pavement surface. Finally, Zone 3 is the dry

contact area where tractive effort is developed. If conditions are such that the tire doesn't have sufficient time to squeeze enough water out for the pavement asperities to come in contact with the tire, then the entire length is in the Zone 1 condition and the tire is actually floating on a film of water (hydroplaning). Most skidding accidents occur at a condition less than that of full hydroplaning and one in which the three zones of contact have developed to varying degrees.

A contribution to the solution of the problem of skidding accidents would be made by creating a condition where the length of the region of tractive force development is at a maximum. This, of course, can be accomplished by reducing the area (Zone 1) of squeezing and initial water film penetration. Investigations have shown that the area of the squeezing zone depends on tire inflation pressure, water viscosity, geometry of tire tread, initial water film thickness and pavement surface texture, the major factor being pavement surface texture. The area of the transition zone is dependent upon both surface texture and dynamic rubber properties. It is the responsibility of the highway engineer to provide pavements with the surface texture necessary to reduce the areas of the first two zones. The major quality of this surface obviously is good drainage characteristics.

Tire-Pavement Friction

When a tire tread element is sliding over a rough-textured pavement, the measured friction force is the sum of

an adhesion force and a hysteresis force, provided that pavement surface geometrics, rubber properties and operating conditions are such that tire wear can be excluded. A thorough discussion of the two components of friction would be quite complex and the author refers those interested to the excellent discussion contained in the report "Tentative Skid-Resistance Requirements for Main Rural Highways" (NCHRP Report 37). Basically, the adhesion component is considered to be the product of interface shear strength and total contact area and the hysteresis component is caused by damping losses within the rubber as it "flows" over and around the mineral particles. Adhesion is more predominant in the dry contact area, whereas hysteresis develops in both the dry and wet areas. Considering the adhesion component only, a gritty, sandpaper-like finish is preferred. Large sharp tip particles in the pavement surface produce a large hysteresis component. In any case, these two components generally occur, to some extent, on all pavement surfaces regardless of the texture.

Considering that two independent properties characterize the frictional performance of pavements, it is logical to classify pavement surfaces by a scale which recognizes friction and drainage properties. Kummer and Meyer propose such classification in their report "Tentative Skid-Resistance Requirements for Main Rural Highways." This classification is shown pictorially in Figure 1. The fact that skid resistance varies inversely with speed is also shown in this figure.

<u>Skid Resistance Measurement</u>

Comprehensive pavement friction measurement should include testing in both the locked wheel condition (skid) and in a condition somewhere between full rolling and full lock (slip). However, the great majority of skid resistance standards are based on a locked wheel condition (which is considered to be the worst condition) and testing in this mode is herein discussed.

A somewhat simple, but hazardous, way to determine skid resistance is to merely bring an automobile up to a given speed, lock the brakes, and after it stops, measure the length of skid. This method of measurement is known as the stopping car distance method and its results are meaningful. It is difficult and sometimes hazardous to perform.

Skid trailers are more and more becoming an accepted standard of field skid resistance determination. ASTM has established a tentative test method for the operation of this type of device (E274-65T). Here the test apparatus is brought to the desired towing speed, water is delivered ahead of the test tire and the test wheel is locked; either or both of the trailer wheels may be involved. The resulting wheel traction force, wheel load, vehicle speed, location and other pertinent data are recorded. The skid resistance of the pavement is then determined from the resulting force information. For all practical purposes, this results in a steady state testing condition. If the ASTM test method is followed, parameters of rubber characteristics, tire load, skidding speed, and water film

thickness are thereby established, and should lead to standardized results. One big advantage to towed trailer skid testers is that they can operate at traffic speeds and therefore the testing function is fast, safe, and of little inconvenience to the motoring public.

Also test more nearly approaches actual operating conditions.

There are instances when laboratory testing of materials or a limited field testing area dictate the use of a small or portable skid tester. There are many such devices available; however, most have the common drawback that they are low speed devices. One portable tester which evaluates the pavements at a higher speed is the California Skid Tester. In this case the small wheel is raised ¼ in. above the test surface, brought to the required speed, and then instantaneously dropped to the test surface. The coefficient of friction is read directly from an attached scale. This device is limited in that it must be calibrated with a towed trailer device to read the coefficient of friction under any specified set of test conditions. An additional limitation, which is true of all portable testers, is that traffic must be blocked for field operations. However, it does have the advantage of being able to test fresh pavement surfaces and laboratory test panels.

Devices such as the British Pendulum Tester, the Penn State Drag Tester, and the New York Thruway Skid Test Cart have been used with varying degrees of success and in some cases acceptable correlations have been obtained with full scale devices. Generally speaking, however, the towed trailer is the

best presently available device for the routine skid testing of in-service pavements. With the addition of certain instrumentation the towed trailer can also be used for testing in the slipping mode of operation.

A discussion of skid testing devices would not be complete without some mention of correlation. Unfortunately, attempts at correlation between various devices has not always been completely successful. This has been true even between similar type devices. It is hoped that conformance to standard test conditions and diligence by various researchers will reduce differences and lead to more meaningful correlations and consequently more universal acceptance of obtained values.

A simple and practical quantitative method to measure surface texture for use in conjunction with skid resistance values is essential in defining the skid resistance characteristics of a given pavement. Presently used methods attempt to measure the "average texture depth." Test methods such as the sand patch test or grease smear test measure the volume of test material required to fill the voids between the pavement asperities. Knowing the area of coverage of the material leads to the calculation of the average texture depth. Stereophotographic and other methods have been used in an attempt to measure surface textures. Advances in this area will greatly aid in updating pavement surface characteristic criteria, particularly if the measurements relate to other surface parameters such as drainage.

Once a pavement surface has been tested for skid resistance, the obtained values must be checked against some

criteria or minimum requirements.

Establishment of Skid Resistance Requirements

Strictly from the standpoint of providing safety on wet pavements, there is no maximum skid number. Here the attribute of practicability must be taken into consideration. When considering methods and materials used to obtain high original skid resistance values, economics must be considered. Providing extremely high skid-resistant pavement surfaces could result in excessive tire wear and noise. Additionally, experience has shown that although some pavements are constructed with high initial skid resistance, this value generally deteriorates with time. Ways to prevent deterioration will be discussed later. Of prime importance is consideration of how much the skid resistance can deteriorate before corrective treatment is necessary. Of course, minimum standards for new construction are also necessary. Either case must not only consider immediate requirements but also the local history of deterioration.

Most minimum frictional requirements have been established by studying skidding accident rates. Various tentative minimum standards have been established on this basis and many researchers are working on improving these standards and expanding the criteria to further include highway geometry into their consideration. It may be that consideration of vehicle and tire design will further refine this criteria. While no responsible national agency has yet specified a minimum skid number, NCHRP Report 37 does suggest a minimum tentative skid number for main

rural highways of 37 measured at 40 mph by ASTM Test Method E274.

In the past, many agencies have taken corrective action on a pavement if the wet weather accident rate reached some pre-designated limit. With the establishment of minimum skid standards, properly related to geometrics, it should be possible to plan for and take corrective action on potentially hazardous pavements prior to the development of high accident rates. Such planning, however, will require extensive programs of skid resistance measurements.

With some knowledge of the characteristics and requirements which lead to a good skid resistant pavement, it is now appropriate to discuss what practical methods can be applied to the construction of adequate, durable skid resistant pavements.

Building Adequate Durable Skid Resistant Pavements

Theoretically all new pavement surfaces should be coarse textured and gritty (see Figure 2 for surface texture terminology used in this section). This is not always economical to accomplish; however, every effort should be made to incorporate as many good friction and drainage properties as possible. It is extremely important, as previously mentioned, to build these characteristics into the pavement so that they will be long lasting.

In good practice, mix design has proven to have the greatest bearing on producing high skid resistant asphalt

concrete pavements. Field construction procedures used in properly spreading and compacting asphalt concrete pavements appear to have very little effect on the resulting skid resistance. Therefore there appears to be little need for a construction control minimum skid number unless the mix control is in the hands of the contractor.

The mix characteristics which affect the skid resistant qualities of asphalt concrete are the physical characteristics of the aggregates and the amount of asphalt. In an effort to produce coarse textured and gritty surfaces, the California Division of Highways specifies, in their standard dense graded mix a combined grading, maximum particle size, and minimum percentage of crushed or naturally angular particles. Permitted loss in the Los Angeles rattler test is specified as an indicator of resistance to traffic wear and pounding. Aggregates used in asphalt concrete mixes in California are relatively polish resistant, so this does not constitute a major problem. However, aggregates which are highly susceptible to polishing should not be used unless covered with a nonpolishing seal coat. The mix design method used in California results in a slightly leaner mix than some other methods. This is particularly important because too much asphalt may create a "bleeding" surface, which usually results in a slippery pavement.

The use of well graded uncrushed gravel will result in a coarse textured but rounded surface (Figure 1). This

type surface has proper drainage characteristics; however, maximum skid resistance is not obtained. Angular aggregate used in too fine a mix will result in a fine textured gritty surface. In this case adequate friction can develop, but care must be taken not to use this type surface in areas of heavy rainfall, as it has poor drainage. As can be seen in Figure 2, the use of rounded aggregate in a fine mix results in a surface with poor high speed skid resistance characteristics. Combined with too much asphalt, with resulting bleeding, this mix type will develop into a slippery pavement.

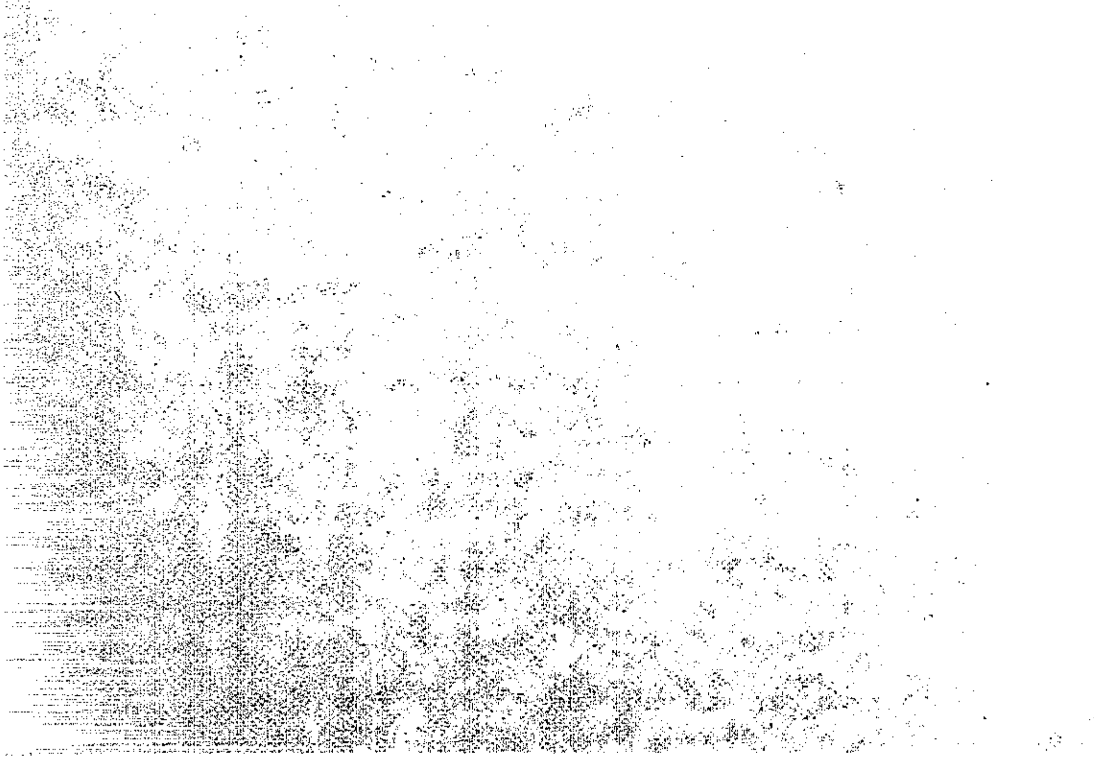
Finishing and texturing techniques are the most important factors in providing portland cement concrete pavements with adequate skid resistance. The object is, basically, to secure adequate texturing during construction, and maintain the texture by using materials and construction practices that insure a durable surface mortar.

In normal practice, PCC aggregate specifications are established primarily to insure structural integrity of the pavement and the resulting surface texture is not considered in the establishment of these specifications. However, as is the case with asphalt concrete, hard durable aggregates must be used. The surface texture is provided normally by some external means. Burlap drag or, preferably, brooming techniques, properly executed, can be applied to obtain a deep texture, with a high initial skid resistance, which could be classified as coarse textured and gritty. Timing of the texturing operation has a great bearing on the effectiveness of the operation. If the

surface mortar is allowed to set before texturing operations, a fine surface texture will result. Any type surface texture produced must be durable. As this is perhaps the most important part of the texturing problem, the surface must not be overworked during the finishing operation. Loss of texture can result in a smooth surface which, like the bleeding asphalt surface, can be hazardous.

Texture can be lost through tire wear, and by the action of abrasives, tire chains, tire studs, salt and freezing and thawing. Studies conducted in California have shown that abrasion resistance is generally proportional to strength. Therefore, any means of increasing the strength of the surface mortar is worthwhile. Strength and abrasion resistance of mortar can, among other ways, be improved by (a) being sure the materials used have the potential to produce quality mortar; (b) increasing the cement factor which is in effect lowering water-cement ratio; (c) minimizing finishing effort, (d) avoiding any surface drying before curing is started, and making sure that curing is not neglected, eliminating additions of water to the surface during finishing; (e) allowing sufficient time for concrete to gain strength before subjecting it to abrasive loads; (f) and where freezing and thawing is encountered, using air entrained mortar.

These factors are all goals of specifications; however, because ideal laboratory conditions do not always exist in the field, compromises must be made. Skill and judgement will



always be required in finishing and texturing operations, but every effort must be made to provide realistic, enforceable specifications. A minimum skid number can be used as an end point specification; however, it must be properly developed by adding to the minimum needed factor to allow for wear.

Certain surface treatments have been demonstrated to be of some value in strengthening the mortar, but this is an after-the-fact approach, and it is believed that efforts should be made to get good mortar during construction rather than rely on such treatments. However, products of this nature may be helpful should these efforts fail.

Restoration of Adequate Skid Resistance to Existing Pavements

If skid resistance studies or high skid accident rates indicate an asphalt concrete pavement to be hazardous due to bleeding, the most successful corrective treatment has been the application of an asphalt concrete blanket. The blanket can be of either the open graded or dense graded type, depending on the particular situation. Aggregate specifications for dense graded blankets should be the same as for new construction. Minimum amounts of crushed or angular aggregates must be specified in open graded blanket mixes. One requirement for open graded blankets is that they be placed on an impermeable surface. An advantage of open graded blankets, in addition to excellent skid resistance characteristics, is that they provide drainage down through the mix and out the sides in addition to surface drainage.

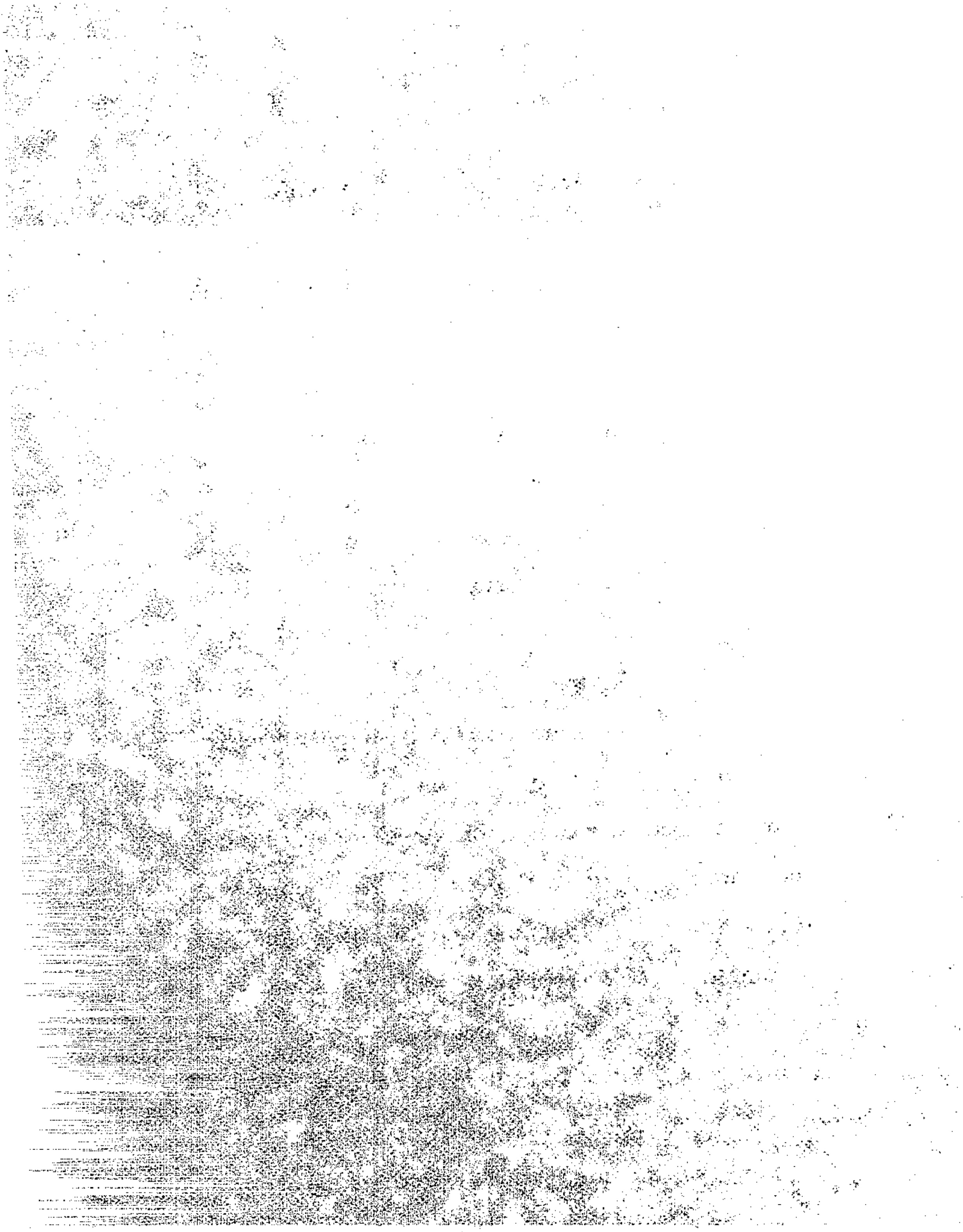
Asphalt concrete surfaces having low skid resistance

caused by wear and polish can be corrected with a asphalt concrete blanket or a screening seal coat. Hard, durable, all crushed or angular materials should be used in screening seal coats. Properly applied, they provide an excellent coarse textured, gritty surface. However, for the same reasons as indicated above, an open graded seal coat is preferable for skid resistance purposes.

Grooving of asphalt concrete pavements has been tried; however, in most cases, traffic action, particularly in warm weather, will tend to close the grooves and make them ineffective. Some asphalt pavements, whose binder has become hard, have been grooved with slight success, but even in this case it is felt that the grooves will close with time.

Smooth portland cement concrete pavements may also be "skid proofed" by the addition of a screening seal coat or asphalt concrete blanket; however, special precautions are needed at the joints. One of the most successful methods of restoring the skid resistance of a PCC pavement is by grooving. Before and after accident studies in California have shown this to be extremely effective. Characteristics of grooving which affect skid resistance are (a) orientation of groove pattern, i.e., longitudinal, transverse, or other; (b) width and depth of grooves; (c) spacing of grooves; (d) and amount of lane width grooved.

California grooves pavements longitudinally on the premise that lateral resistance to skidding on curved alignment



is improved, due to a "tracking" effect, over that of transverse or diagonal grooving. On the other hand, the English groove transversely, to obtain a higher longitudinal skid resistance, but also to cause faster transverse drainage of the surface. California had previously settled on using grooves 1/8 inch (0.125) wide, but recently patterns have been cut with 0.095 inch wide blades. In the original investigations of PCC pavement grooving, a few patterns were placed with 1/4 inch wide blades; however, they resulted in riding discomfort to motorcyclists and small car operators, and their use was therefore discontinued. A recently completed study in California has shown that patterns using 1/8 inch and 0.095 inch wide cuts do not present hazardous riding conditions to motorcyclists.

To be effective, grooves should be a minimum of 1/8 inch deep and, in California, a 3/4 inch spacing is the most predominate spacing used. Wider spaced, longitudinal grooves, although providing drainage channels, result in very little increase in skidding resistance. Grooves spaced closer than 3/4 inch do not show sufficient increase in benefit to be worth the added cost.

If a PCC pavement is highly polished and requires a large increase in coefficient of friction, a pattern which utilizes very shallow cuts, spaced between the main cuts, is very effective. A molded head type pattern, which re-textures the entire pavement surface, can also be used in this case.

Essentially, in California, the entire lane width is grooved, omitting only about 12 inches adjacent to each lane line or edge of pavement. This is done to preserve the lane line or markers, and also to permit the use of vacuum devices which remove water and cutting residue concurrently with the grooving operation. This practice greatly reduces the hazard to traffic during the grooving operation.

Some of the ramifications of the skid resistance problem have been discussed, with particular emphasis on restoring the pavement surface. This has been done in an attempt to provide a general knowledge of the complexities of just one aspect of a major highway safety problem. Any of the areas discussed can be dealt with in much more detail, and much work remains to be done in all of the areas. It is hoped that the engineering profession will make rapid progress in the solution of this problem in its continuing efforts to provide the motoring public with safe highways.

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December 19, 1969

Mr. Kneeland A. Godfrey, Jr.
Editor, Civil Engineering - ASCE
United Engineering Center
345 East 47th Street
New York, N. Y. 10017

Dear Mr. Godfrey:

Pursuant with your request of August 18, 1969 there is enclosed a suggested article for Civil Engineering titled "Skidding on Highways, Preventive and Curative Measures."

I am sorry I was unable to meet the deadline of December 15, but I hope that it is not too late for your use. If there is anything further I can do, please let me know.

Very truly yours,

Original Signed
JOHN L. BEATON

JOHN L. BEATON, P.E.
Materials and Research Engineer

JLB:fg

Encl.

AIR MAIL

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