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SLIPPERY PAVEMENTS

BY

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Introduction

The term "slippery pavement" has been defined by Kummer and Meyer[1] in their report titled "Tentative Skid-Resistance Requirements for Main Rural Highways". They state that "Although it is generally true that a slippery pavement is conducive to skidding accidents, it is by no means correct to assume that a skidding accident automatically indicates pavement slipperiness. Skids that are due to excessive speed, smooth tires, unbalanced brakes, poor geometric design of the highway, or a "rough" or inattentive driver jerking the steering wheel or slamming on the brakes, cannot be blamed on the pavement surface. On the other hand, skids that take place at normal traffic speeds with well-treaded tires and vehicles in good mechanical condition, particularly if they re-occur at the same location, most definitely suggest pavement slipperiness. Thus, when the term slippery pavement is used it is with the understanding that all other factors involved are normal or nearly so and that they do not significantly contribute to any skidding which might occur".

It is probable that from a technological viewpoint, the slipperiness problem could be solved by improved geometric design of highways, improved specifications and construction procedures for road surface textures, improved design of tires and vehicles, rigid inspection procedures that would keep vehicles with smooth tires and faulty brake and suspension systems off the road, and the adoption and enforcement of different speed limits for dry and wet conditions as well as

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1. Highway Research Board NCHRP Report 37.

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for day and night-time driving. How many of these things can be implemented, of course, depends upon the economics involved, as well as the technical solutions. It is probable that the automobile and the driver are the most important factors involved in any skidding accident. However, insofar as this discussion is concerned, it is limited to pavement slipperiness rather than the overall field of skid accidents.

As such then it appears to me that the subjects of importance are: measurement of pavement friction, development of realistic skid resistance coefficients, reconditioning of worn pavements so as to improve their friction levels, construction techniques to insure specific friction levels of new pavements, pavement wear and the factors involved in specifying aggregate and construction quality requirements so as to lengthen the service life of our pavement surfaces, and interface characteristics between the tires and wet pavements.

Any discussion of skidding should consider the NASA[2] work in separating the two different types of loss of traction on wet surfaces, namely viscous and dynamic hydroplaning. Viscous hydroplaning occurs when a thin fluid film is on the pavement, and presently used methods of measurement for skid resistance deal with this form of loss of traction. Dynamic hydroplaning occurs when the pavement has a substantial thickness of water, approximately 0.2 inch, on the surface. Present methods of measurement do not provide an adequate indication of potential dynamic hydroplaning. One of the most important problems connected with loss of traction by viscous hydroplaning is the determination of a minimum coefficient of friction value for remedial action.

Measurement of Pavement Friction

While the California Division of Highways has recently purchased and are starting to use a lock wheel skid trailer conforming to ASTM-E274, all of our work up to the present has been done utilizing our California Skid Tester.[3]

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2. Horne, Walter B., and Leland, Trafford J. W., "Influence of Tire Tread Pattern and Runway Surface Condition on Braking Friction and Rolling Resistance of a Modern Aircraft Tire." NASA TN D-1376, 1962.

3. Hveem, F. N., Zube, E., and Skog, J., "California Type Skid Resistance Tester for Field and Laboratory Use". Proceedings First International Skid Prevention Conference, Part II, 1959.

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The California Skid Tester used in determining the coefficient of friction of pavement surfaces is a portable device which was calibrated against a towed trailer constructed by Professor R. A. Moyer of the University of California.[4] Previous studies by Moyer and others, indicated that the lowest skid resistance value for any given surface would be attained when the brakes are locked on a vehicle having smooth tread tires on a wet pavement with speeds around fifty miles per hour. It was felt that the California Skid Tester should be calibrated to simulate the worst conditions encountered by traffic. Therefore, in the correlation test program, the coefficient of friction values obtained from the Moyer unit using locked wheels, smooth tires, wet pavement and a speed of fifty miles per hour were compared to our readings obtained with a smooth tire, wet pavement and a tire speed of fifty miles per hour.

Development of Skid Resistance Coefficients

In order to make effective use of test results derived from any form of skid test apparatus, the engineer must be provided with recommendations on minimum requirements for deciding on the necessity for remedial action. It is interesting to note that there is a large volume of literature on skid resistance measurements, but few recommendations for critical values that would be of aid to the engineer who must decide whether steps should be taken to improve the skid resistance of a given road surface. Remedial action must be taken before the road surface is excessively slick, so any value must be set high enough to allow for programming and accomplishment of the repair.

During the period of 1950 to 1958, Professor Moyer determined the skid resistance of a large number of different pavements in the road system of the California Division of Highways.[4 & 5] On the basis of this survey it was decided to tentatively use a value of 0.25f for a minimum value.

Since our available information on accident frequency correlation with skid resistance of the surface was very limited, it seemed desirable to obtain as much information as possible from the studies of other investigations.

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4. Moyer, R. A., "Recent Developments in the Measurement of Road Roughness and Skid Resistance". Proceedings of the Association of Asphalt Paving Technologist Vol. 20, p. 42, 1951.

5. Moyer, R. A., "Effect of Pavement Type and Composition on Slipperiness, California Experience". Proceedings First International Skid Prevention Conference, Part II, 1959.

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Two of the most complete studies are from the work of C. G. Giles in England and T. E. Shelburne in Virginia. Unfortunately the equipment used in these studies was different from that used by us. In order to make use of information attained by Giles and Shelburne, we obtained a British Portable Tester which was used in a comprehensive accident analysis in England by Giles,[6] and attained a correlation with the California tester. Also, D. C. Mahone[7] presents a correlation between the British Portable Tester and the Virginia test car. This correlation permits a comparison with the lowest coefficient proposed in Virginia as well as in England as shown in Figure 1.

The analysis leads to the conclusion that California pavements having California tester skid resistance values above 0.30f should definitely be satisfactory. Based on the fact that England and Virginia receive more rains than California it seems logical to conclude that readings on the California tester above 0.28 should be satisfactory for probably all sites with the possible exception of curves. This correlates reasonably also with Marshall's[8] work in Florida and other work in Virginia.[9]

The above noted correlations were very encouraging, and it was decided to initiate further studies involving skid resistance measurements at wet weather accident sites on California highways. Unfortunately the California Highway Patrol accident report does not require the officer to determine if skidding was involved in the accident. However, the officer, in his observations, may note that skidding was a factor in the accident. Therefore, accidents occurring during wet weather involving only one vehicle with no recorded defects for either driver or the vehicle were selected from all reported wet weather accidents. Test sites were selected for this

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6. Giles, C. G., Sabey, B. E., and Cardew, K. H. F., "Development and Performance of the Portable Skid Resistance Tester". British Road Research Laboratory Technical Paper No. 66, 1964.

7. Mahone, D. C., "A Correlation of the British Portable Tester and the Virginia Skid Test Car". Virginia Council of Highway Investigation and Research, May 1961.

8. Marshall, A. F. Jr., "Skid Characteristics of Florida Pavements Determined by Topley Decelerometer and Actual Stopping Distances". Highway Research Board, January 1962.

9. Mills, J. P., and Shelton, W. B., "Virginia Accident Information Relating to Skidding". Proceedings First International Skid Prevention Conference, Part I, 1959.

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survey on the basis of a concentration area which is defined as an area of three accidents within 0.1 mile. A number of these sites were chosen for skid testing. Other testing work has also been performed at sites selected by our District traffic departments on the basis of wet weather accident information. The results of this investigation showed the average friction value to be 0.22f with none above 0.28f. It is interesting to note from Figure 1 that 0.28f is the same as the British minimum for all sites.

Improving Skid Resistance of Existing Pavements

Providing and maintaining a skid resistant surface is a very important factor in the performance of any highway. All types of pavement surface will eventually show some reduction in coefficient of friction values during their service life. This reduction is caused by wear and polish of traffic, especially by heavy trucks.

Bituminous Pavements are normally "skid proofed" by the placing of a chip seal or an "open graded" seal. This practice has been very successful on California highways as illustrated in Figure 2. However, several years ago the California Division of Highways became aware that some sections of concrete freeways, especially on curves, were having an unusual number of accidents occurring during wet or rainy weather. After considering the use of acid treatment on the surface or the application of a coal tar-epoxy screening seal coat, it was decided to study the effect of grooving the pavement.

Grooves may be cut in the pavement in either a longitudinal (parallel to the centerline), transverse direction, or diagonally. Practically all of our grooving to date has been performed in a longitudinal direction. We are of the opinion that this leads to increased lateral stability, and tends to guide the vehicle through a critical curve area. This has been confirmed by studies performed in Texas.[10] However, studies in England[11] indicate that grooving perpendicular to the centerline is better overall practice, and further effort will be required to resolve the problem.

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10. McCullough, F., "Slick When Wet and Field Evaluation of the Saw Cut Method". Texas Highways - Vol. 10, No. 1, p. 9, 1963.

11. Blake, L. S., "Recent Research and Development on Concrete Roads, 1964-1967". The Concrete Society, Limited Terminal House, Grosvenor Gardens, London.

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Groove patterns vary. The most common type is rectangular in form and may be varied in width and depth and distance between centers of grooves. Other types have rectangular form, but the bottom is partially rounded, and the edges at the pavement surface are also rounded. Others have a large V cut separated by smaller V cuts.

A number of patterns have been used in our serration work to date.[12 & 13] This was done in order to determine the increase in the friction factor, wear resistance, and possible vehicle handling problems. In all cases the grooves are all in a longitudinal direction. Figure 3 shows the effect of grooving on the average coefficient of friction value for the various PCC pavement projects.

A very important characteristic of any treatment for raising the existing friction value is its resistance to wear and polish of traffic. Results of friction measurements with time on various grooved projects are shown in Figure 4. Not enough time has elapsed on the majority of the projects to draw any firm conclusions. It appears, however, that the nature of the aggregate and mortar strength may influence the resistance to wear and polish of the grooved areas.

A Before and After accident study of our grooving projects to date indicates that the total accidents were reduced 62 percent. Of this, wet pavement accidents were almost completely eliminated (90 percent) and dry pavement accidents dropped 21 percent.

On seven jobs in our District 07 (L.A. area) the cost of grooving was in the range of seven to nine cents per square foot. In some other Districts the cost is somewhat higher. The best average is approximately ten cents per square foot.

Motorcycle and light car tests clearly indicate that ¼" x ¼" grooves will create problems in vehicle control. It is suggested that cuts no greater than 1/8" x 1/8" be

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12. HRB Special Report 101.

13. Farnsworth, E. F., "Pavement Grooving on Highways". Langley Conference, NASA SP-5073.

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used if vertical grooves are cut in the pavement. 1/8" deep x ¼" wide V grooves do not appear to create any problems. Further studies are required before any specific spacing can be recommended. However, since approximately equal accident reductions were noted for 1/2" and 3/4" spacing it is suggested that 1/8" x 1/8" on 3/4" centers be used. Recent studies tend to indicate that a slightly narrower groove, 0.95" (3/32") on 3/4" centers may be better for motorcycle traffic. This pattern is being used in the Los Angeles area on an experimental basis.

Dynamic Hydroplaning

Essentially, dynamic hydroplaning may be defined as the condition under which the tire footprint is actually lifted off the pavement by the action of fluid pressure and then rides on a fluid film of some finite thickness. Dynamic hydroplaning has been studied mainly by those concerned with wet weather landings of high speed aircraft.[14] However, some authorities believe that dynamic hydroplaning may be a factor in uncontrolled skids of automobiles during periods of heavy rainfall, at least those occurring at high speeds with bald tires.

The important parameters of significance to dynamic hydroplaning of aircraft, automobiles, or trucks are the speed of the vehicle, tire inflation pressure, tire condition, depth of water and surface texture.

We have completed a preliminary analysis in an attempt to determine the importance of dynamic hydroplaning as a cause of accidents. In order to try to eliminate as many causes as possible only single car accidents in 1964 and during periods of actual rain were analyzed. This was the latest year that records were available when the analysis was started in 1966. During the year 1964 there were 13,917 wet pavement accidents which was 9.7% of all accidents. There were 9,480 accidents during actual rain or 6.6% of all accidents. Of the accidents occurring during rain there were 1,705 which involved only a single vehicle. These were selected for further analysis and the Highway Patrol reports were carefully studied. A study of the reports showed that 152 accidents out of the 1,705 occurred during heavy rainstorms, where the possibility of a sizeable thickness of water cover might exist on the pavement. Information on these accidents is shown in the following table:

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14. Horne, W. B., Yager, T. J., and Taylor, G. R., "Recent Research on Ways to Improve Tire Traction on Water, Slush or Ice". AIAA/RAeS/JSASS Aircraft Design and Technology Meeting, Los Angeles, November 15-18, 1965.

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Speed						Road Section		Tire Condition		Vehicle	
20 30	30 40	40 50	50 60	60 70	70 80	Tan-gent	Curve	Not Stated	Smooth	Compact	Stan-dard
3	12	34	60	42	1	85	66	112	37	38	114

Total Accidents = 152

Of these 152 accidents Highway Patrol reports in seventeen cases mention water on the pavement in the form of puddles or hydroplaning as the accident cause. The fact that a sizeable number of the accidents in the potential hydroplaning group were traveling at speeds in the range of 50-70 mph indicates that excessive speed for the very poor weather conditions may have been a very responsible factor in either directly causing the accident or indirectly influencing the tendency of the vehicle to hydroplane.

Specifications and Construction

Pavement slipperiness depends primarily on two factors - coefficient of friction and texture of the surface. During construction it is important to build these features into a pavement with such durability that they will last. Measuring devices are now available for determining the coefficient of friction so a value can be specified as an end point requirement in the contract. Such a value must be set to satisfy local conditions, recognizing that the number must be high enough so that a reasonable service life can be attained. All pavement surfaces wear under traffic depending on amount of traffic, the materials, and construction procedures.

Texture of a pavement[15 & 3] is still an unresolved problem although a great deal of work is underway in this area. A deep, durable texture constructed to last and provide a rainwater reservoir would be ideal to solve the skidding problem. Unfortunately this could cause other problems such as excessive tire wear and noise and diminished visibility due to splash and throw of the surface stored water.

At the State level here in California[15] we treat bituminous and portland cement concrete pavements differently. Our asphalt pavement construction is controlled by a combination end point quality and method specification using a mix

15. HRB Special Report 101.

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design which we know by experience will give a nonskid surface. Our experience indicates that such pavements when new will have a coefficient of friction slightly below 0.33 but after a year or so (depending on traffic) it will raise above 0.33 and stay at a uniform level for several years (California's aggregates have excellent nonskid properties).

Portland cement concrete pavements are controlled by an end point coefficient of friction of 0.30 and the texture is controlled by requiring finishing with a burlap drag. This method specification does not always provide the texture desired so we are attempting to develop a proper end point test that will measure a specified texture. Such a test combined with our coefficient of friction should result in a nonskid pavement at least while the pavement is new. Our past experience indicates that weak surface mortars can wear rather rapidly so we are also developing a wear and polish machine so as to provide a means to measure a specification limit for durability.

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Figure 1

CORRELATION STUDIES
MINIMUM FRICTION VALUE

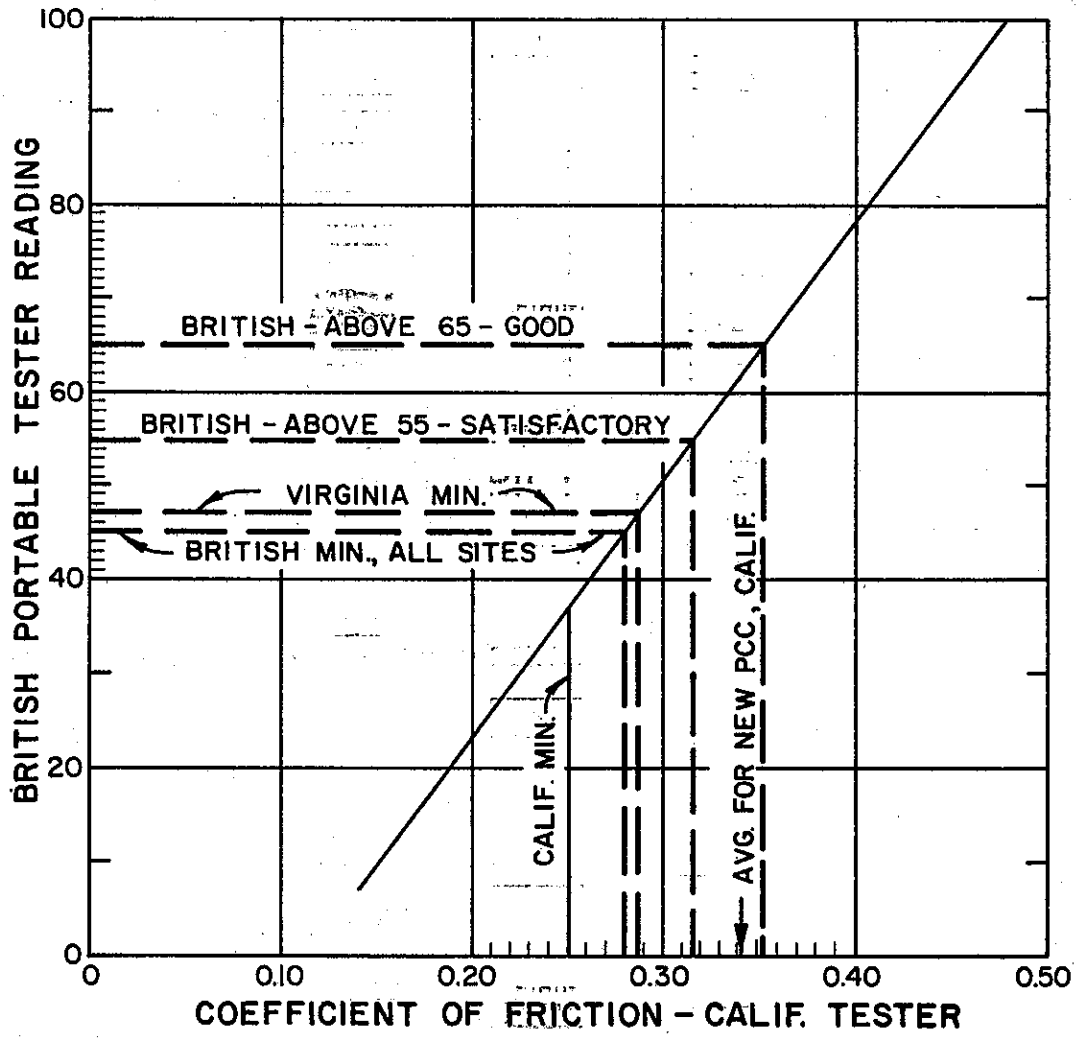

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Figure 2

TRANSVERSE FRICTION VALUES

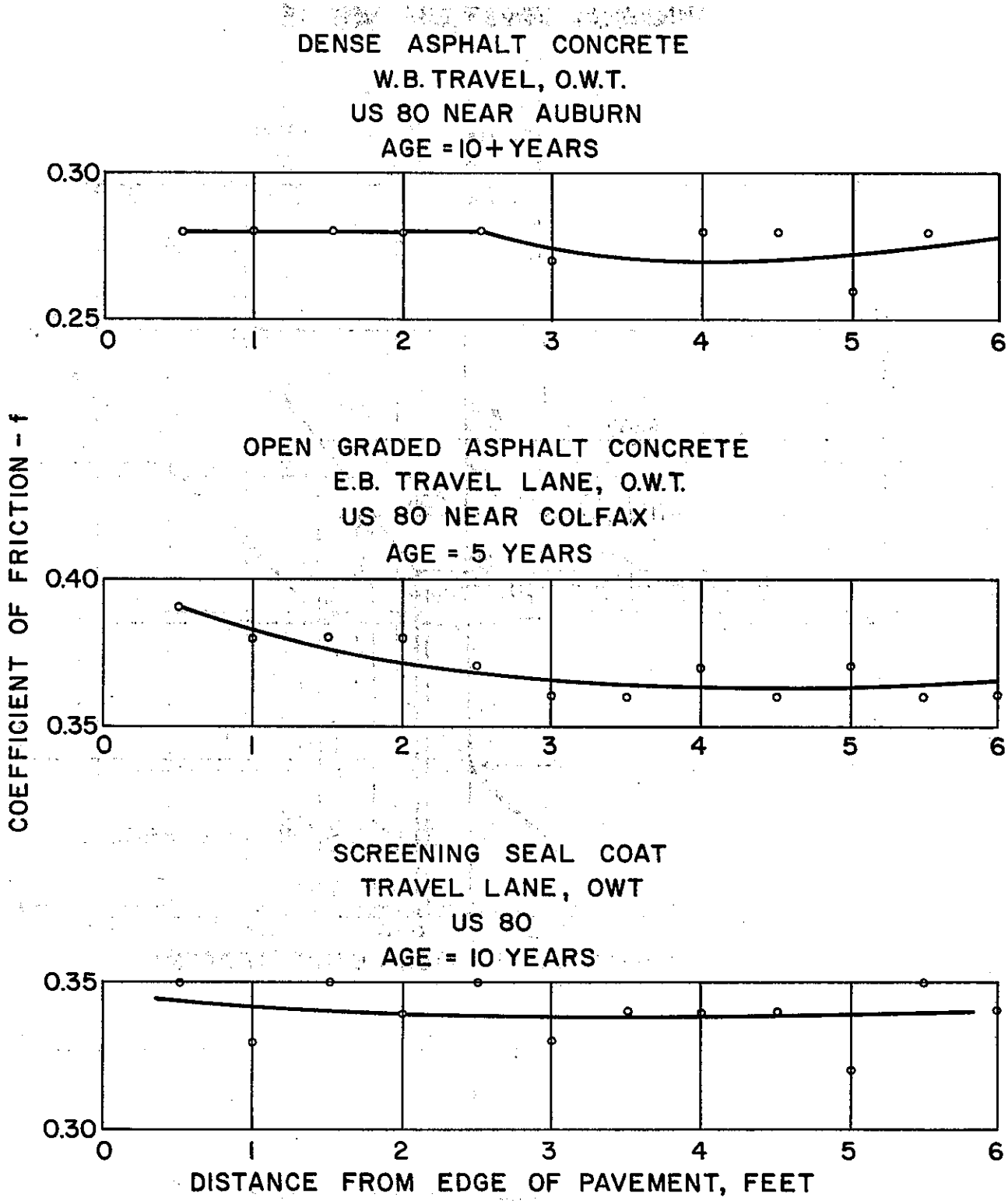

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Figure 3

EFFECT OF GROOVING PATTERN ON AVERAGE COEFFICIENT OF FRICTION VALUE OF PCC PAVEMENTS

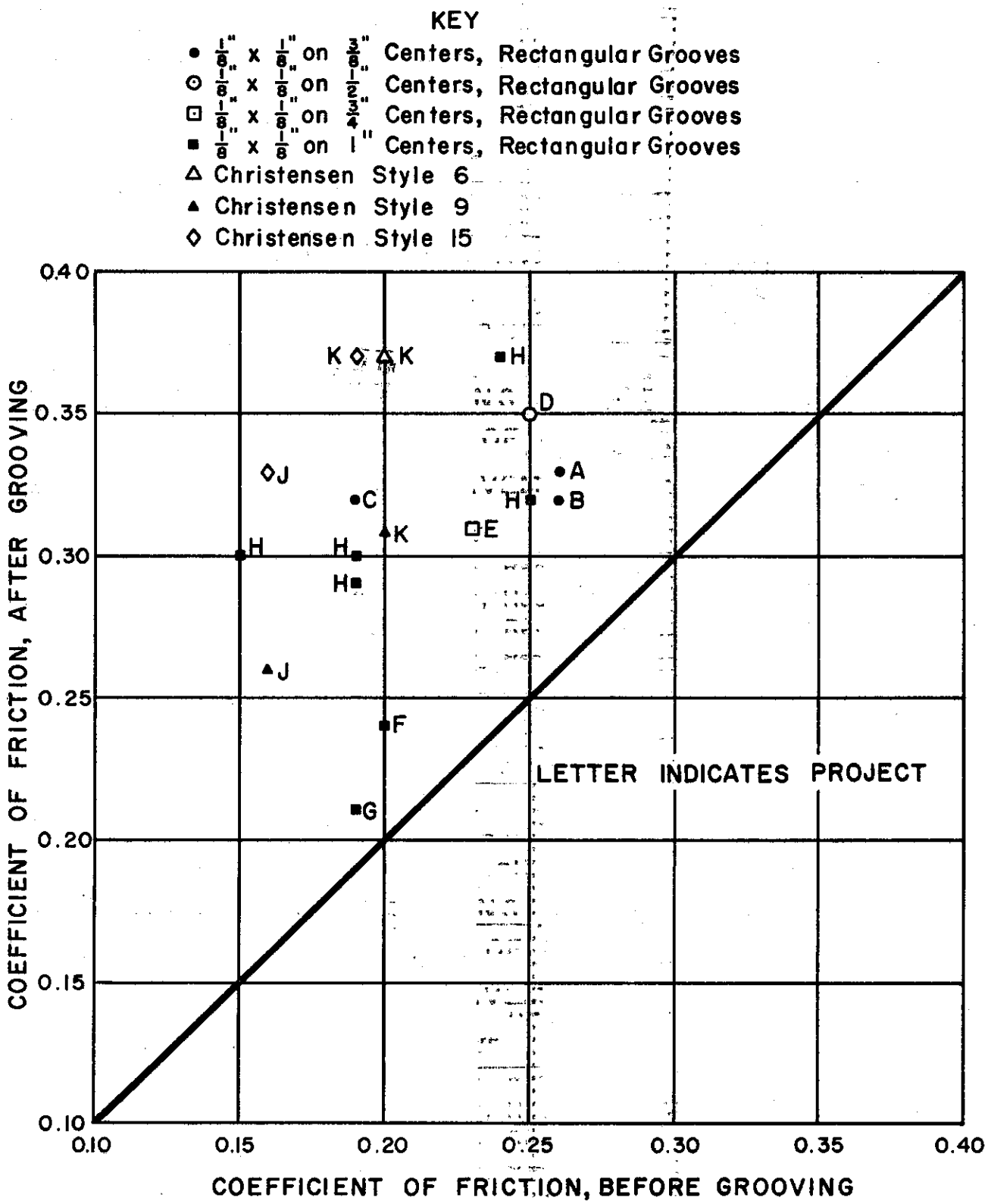

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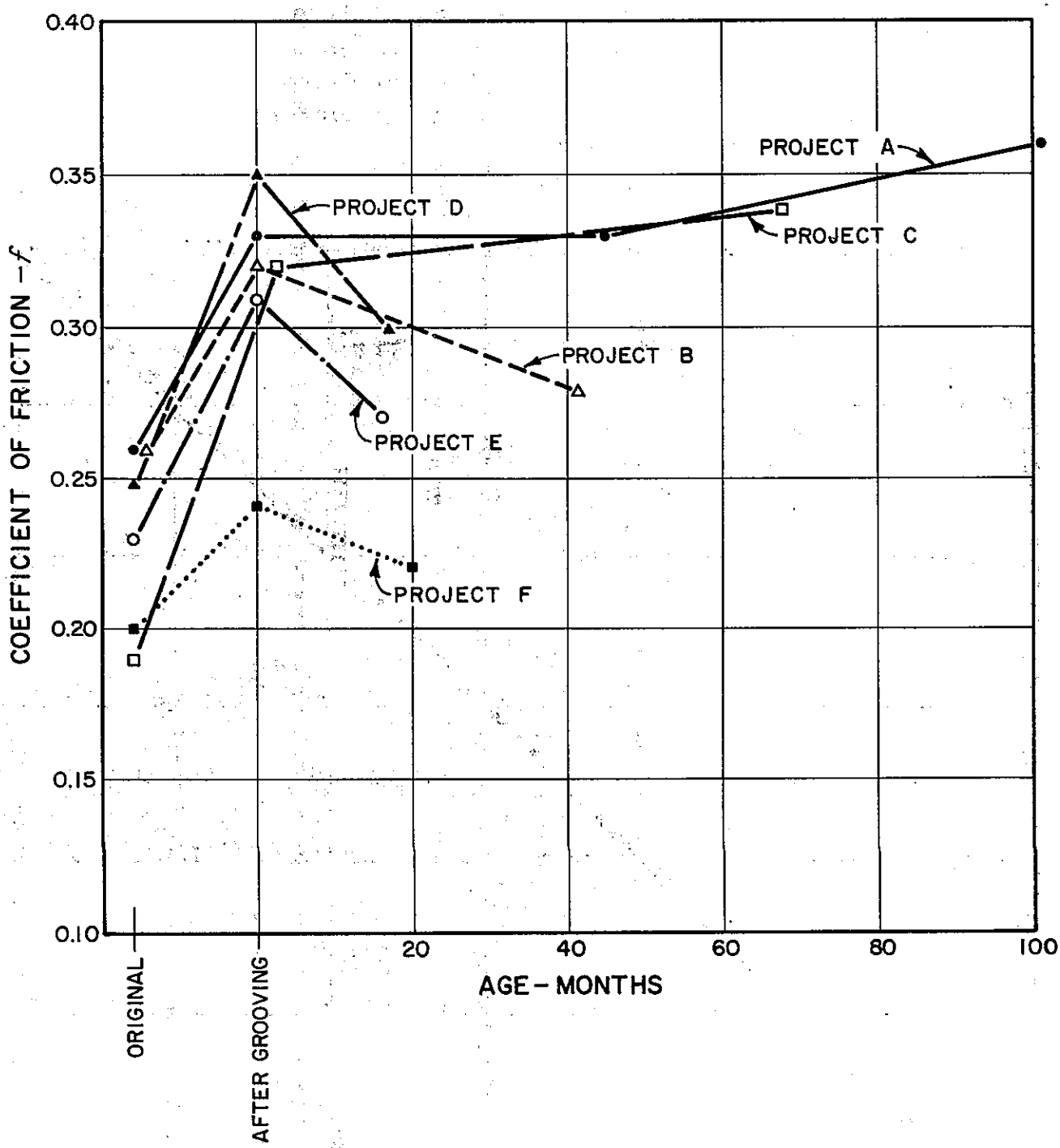
Figure 4

CHANGE IN FRICTION VALUES FOLLOWING GROOVING OF PCC PAVEMENTS



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