A Strategy for Reducing Wet Pavement Accidents in Illinois

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16. Abstract
In Illinois a disproportionate number of wet-weather accidents are associated mostly with intersections, curves, hills, railroad crossings, and interchange areas where a driver's maneuver demand exceeds the available pavement friction. Review of 226 such sites indicated that friction numbers (FN) ranged from 18 to 53. Of the total number of sites, 59 percent had an FN below 30, and 34 percent ranged between 30-36 while only 7 percent exceeded an FN of 36. An equally important finding was that one-third of the high-accident sites not having a disproportionate number of wet-pavement accidents also had friction numbers below 30.

A long-term strategy for reducing wet-weather accidents involves upgrading and prolonging friction characteristics in new as well as in existing pavements. Recent specification changes limit the use of crushed stone and require either slag or a 50-50 blend of slag and crushed dolomite or slag and crushed gravel in bituminous surface courses depending on highway class and traffic volume. A portland cement concrete special provision requires that the final finish be obtained by use of an artificial turf drag immediately followed by a mechanically operated metal-comb transverse grooving device. In existing surfaces, friction can be improved by bituminous resurfacings containing coarse aggregates with high friction characteristics or by grooving, planing, milling, profiling, repaving, and acid etching. Sometimes, wet-pavement accidents can be reduced by lowering driver demand instead of improving friction characteristics.

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A STRATEGY FOR REDUCING WET-PAVEMENT ACCIDENTS IN ILLINOIS

By

Philip G. Dierstein

Interim Report
IHR-86
Skid Resistance of Pavement Surfaces

A Research Study Conducted by
Illinois Department of Transportation
Springfield, Illinois 62764
in cooperation with
U. S. Department of Transportation
Federal Highway Administration

May 1977

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A STRATEGY FOR REDUCING WET-PAVEMENT ACCIDENTS IN ILLINOIS

INTRODUCTION

Vehicle skidding, which involves not only the vehicle but also the pavement and the driver interacting in a changing environment, falls into the situation hazard category. A situation hazard is a combination of conditions with or without object hazards, which may be either fixed or moving. In situation hazards, the elements (vehicle, driver, pavement, and environment) by themselves may not necessarily be hazardous, but when combined they are treacherous and can cause accidents. During rainfall for example, driving a vehicle with smooth tires over a polished, curving roadway, which has insufficient superelevation, can create a situation hazard that leads to a number of skidding and single-vehicle run-off-the-road accidents. Sometimes, situation hazards can be eliminated by changing a wearing surface, while at other times, the roadway may need a complete redesign to eliminate a hazard (1).

Research has established that wet pavements have about one-half the skid resistance of dry pavements (2). Yet, according to the National Safety Council, only one-third of the wet-pavement accidents involve skidding, and observations indicate vehicle skidding does not always result in a reported accident. Nonetheless, wet-pavement accident rates are significantly greater than mean-accident rates, and up-grading pavement friction indeed can help reduce wet-pavement accidents (3).

Recognizing a need for reducing wet-pavement accidents, the Illinois Department of Transportation, in cooperation with the Federal Highway Administration, undertook research in 1966 which characterizes the friction of new and existing street and highway surfaces. The general objectives of this research were:

(1) To develop new equipment or improve existing equipment for determining the friction characteristics of highway pavements, intersections, and interchanges.

(2) To determine the friction characteristics of existing highway pavements, intersections, and interchanges.

(3) To study the polishing characteristics of aggregates used in highway pavements.

(4) To develop durable and economical means of increasing pavement friction.

(5) To assemble a more positive body of knowledge concerning pavement friction.

The study was conducted in five phases, each answering one of the objectives. The equipment developed in Phase 1 measured the friction of pavement surfaces evaluated in the remaining phases, and the findings (4, 5) in Phases 2, 3 and 4 helped shape the strategy presented in this report (Phase 5).

Since 1966, much information about pavement friction has been assembled in Illinois and elsewhere. As this body of information has grown, Illinois has limited the use of crushed limestone in bituminous concrete and has improved texturing in portland cement concrete (PCC) pavements which, over the long term, should upgrade statewide pavement friction and lessen wet-pavement accidents.

This report discusses pavement friction requirements, presents recommendations for design and construction of new surfaces, offers ways of restoring pavement friction in existing surfaces, and suggests ideas for lower frictional demand. The term FN (friction number) in this report replaces SN (skid number), which refers to the locked-wheel skid number obtained with a skid trailer meeting the requirements for ASTM Designation E264-70.

PAVEMENT FRICTION REQUIREMENTS

According to Farber et al. (6), "A pavement can be considered deficient in skid resistance only in relation to the demand of traffic on it. Skidding will occur on a dry pavement of high skid resistance if a sufficient violent maneuver (such as braking to a stop from 60 mph in 100 ft, or negotiating a 200-ft radius curve at 60 mph) is attempted. Such demands can arise in an emergency or as a result of extremely poor driving, but the resulting skidding cannot be blamed on the pavement. It is only when skidding occurs as a consequence of maneuvers that are within the range of normal demand (accelerations, braking and cornering by a majority of drivers under normal traffic conditions) or intermediate demand (last-minute braking or steering corrections caused by inattention, misjudgement, or unusual incidents) that the pavement skid resistance should be considered inadequate. Neither can skidding under normal braking and cornering on a wet pavement with adequate skid resistance be attributed to the pavement if the vehicle is deficient in such respects as bald tires, improper brake adjustment, faulty steering components, poor suspension, etc."

Because of the complex interactions that occur in the driver-vehicle-roadway system, no standards for friction numbers exist. Kummer and Meyer (2) have recommended that a tentative minimum FN_{40} of 37 should satisfy the minimum frictional demand when the mean vehicle speed is 50 mph (80 Km/h), but one value applied to all surfaces is believed an unrealistic approach in reducing wet-pavement accidents. Because frictional demand along the roadway changes continuously, it may be either less than or greater than actual pavement friction. Sometimes, accidents can be reduced just by lowering frictional demand without physically changing a roadway, but usually some physical change is required.

This section discusses control principles associated with wet-pavement accidents and examines deterioration of pavement friction.

Control Principles

Skidding occurs mostly during rainfall when relevant information unnoticed or ignored by the driver may cause him to select an inappropriate speed or path. Slippery pavements can be identified two ways: high-accident rates, which flag sites as they become hazardous, and friction inventories, which identify potentially slippery surfaces before they become hazardous. Regardless of the method, both procedures involve measuring pavement friction, which is just one of several factors used in selecting a choice of action.

Currently, the first warning of insufficient friction occurs when a disproportionate number of wet-pavement accidents happen at a specific place. As hazardous sites are identified, their investigation should include, at least, a review of historical data and a site survey (1, 7). In addition to this, an investigator may need to observe and to assess operations as well as to collect performance data. When all this information has been gathered, the probable causes, which may consist of one or more highway condition hazards (any place where the state or condition of the roadway causes the driver to use extra caution) coupled with situation hazards, usually can be identified. Once a problem is identified, improvements based on engineering investigations are recommended by the Districts. The Highway Safety Construction Committee comprised of representatives of the Division of Traffic Safety and the Bureaus of Traffic, Design, and Programming decides whether an improvement submitted by the Districts will be programed for construction.

Annually since 1972, the Division of Highways has identified accident sites where skidding on wet pavements may be suspected as a contributing factor. Originally, the criteria used in selecting sites considered places where the critical accident rate has been exceeded and where 50 percent or more of the accidents involved either a wet-pavement or a rear-end collision or a vehicle running off the road or any combination of the three factors. Later, the criteria were modified. To qualify now, sites exceeding the critical accident rate not only require that approximately 60 percent or more of the accidents involve either a wet-pavement or a rear-end collision or a vehicle running off the road, but also require that approximately 33 percent or more of the accidents involve a wet pavement. Both the original and the present criteria exclude any accident occurring on ice and snow-covered pavements. After sites are identified, friction tests verify whether a low friction level is associated with the accident site.

Having these data provided an opportunity to identify the friction level below which disproportionate numbers of wet-pavement accidents occur. The three friction levels currently used as guides in evaluating pavements at high-accident locations in Illinois are: Above 36, 30-36, and Below 30. When pavement friction is above 36, probably some condition other than pavement friction may be the primary factor causing accidents; when the value lies between 30 and 36, uncertainty exists as to whether pavement friction is the primary factor; but when the value is below 30, pavement friction probably is a contributing factor to the high accidents and should be upgraded as a part of the corrective action.

Kummer and Meyer (2) say that slippery pavements can be identified by computing a skid-trap ratio: $R_t = (Aw/Ad)\ (Dd/Dw)$

in which: Aw = number of accidents occurring when the surface is wet;

Ad = number of accidents occurring when the surface is dry;

Dw = number of days on which the surface is wet;

Dd = number of days on which the surface is dry.

Whenever the ratio exceeds unity (wet-pavement accidents normalized with respect to dry and wet days exceeds dry-pavement accidents) the existence of a skid trap should be suspected, and pavement friction characteristics may be suspected as a possible contributing factor to wet-pavement accidents.

Kummer and Meyer (2) also say that the ratio seems more sensitive when summer and fall accidents are used instead of accidents for the entire year. For this reason, the analysis period used in this study began in April and ran through October. Monthly climatological data prepared by the National Oceanic and Atmosphere Administration summarize the number of days precipitation occurs into three categories: .10 in. (3 mm) or more, .50 in. (13 mm) or more and 1.00 in. (25 mm) or more. The number of days that 0.10 in. (3 mm) or more rainfall occurred was selected arbitrarily as the number of days a surface was considered wet, realizing that the pavement may be wet only part of that time. Because both accidents and rainfall can be considered random events, 1970 and 1972 data were combined with 1971 data to obtain a more reliable skid-trap ratio. Knowing that pavement friction decreases with time and varies seasonally, the friction numbers obtained at each site in 1972 still were assumed representative of 1970 and 1971 friction levels.

Of the 166 high-accident sites available for study (Table 1), 62 were rural primary highway intersections, where traffic control devices required stopping;

TABLE 1. SUMMARY OF HIGH-ACCIDENT SITES

Location	Ratio > 1	Ratio ≤ 1	Total
Rural Primary System			
Intersections	39	23	62
Open highway	55	24	79
Rural Interstate System			
Open highway	16	9	25
Total	110	56	166

79 were rural highway sections, associated mostly with curves, hills, and railroad crossings; and 25 were rural interstate sections mostly involving easy curves and gradients and a few interchanges. About one-third of the sites had a skid-trap ratio less than unity, which suggests that factors other than pavement friction probably were associated with accidents at these sites. This left 110 sites, which had a ratio exceeding unity, available for study.

More recently, in 1975, friction inventories were conducted on the Stevenson, Edens, and Kennedy Expressways in the Chicago Metropolitan Area. An analysis comparing wet- and dry-pavement accidents (1973-74) to average friction numbers by 1/4-mi. segments produced another 312 sites. Of these, 116 had skid-trap ratios exceeding unity and were included in the analysis.

After accumulating 226 sites, a relative frequency histogram, having a class interval of three friction numbers from 18 to 53, was constructed and can be seen in Figure 1. The array of sites indicates an asymmetrical distribution skewed right. The histogram indicates that 59 percent of the sites had an FN below 30 while 34 percent ranged between 30 and 36 and 7 percent were above 36. Although no friction number emerged as a point above which a disproportionate number of wet-pavement accidents ceased, a marked increase in high-accident sites occurred when the FN fell below 33, which is only 3 numbers above the current low level of 30. Another equally important finding was that one-third of the high-accident sites not having a disproportionate number of wet-pavement accidents also had friction numbers below 30. Evidently, driver maneuver demand at these places was lower than the corresponding available pavement friction.

As a further refinement, the sites were grouped by rural intersections, rural open highways, and metropolitan expressways. Relative cumulative frequencies were constructed for each group and are shown in Figure 2. These curves indicate

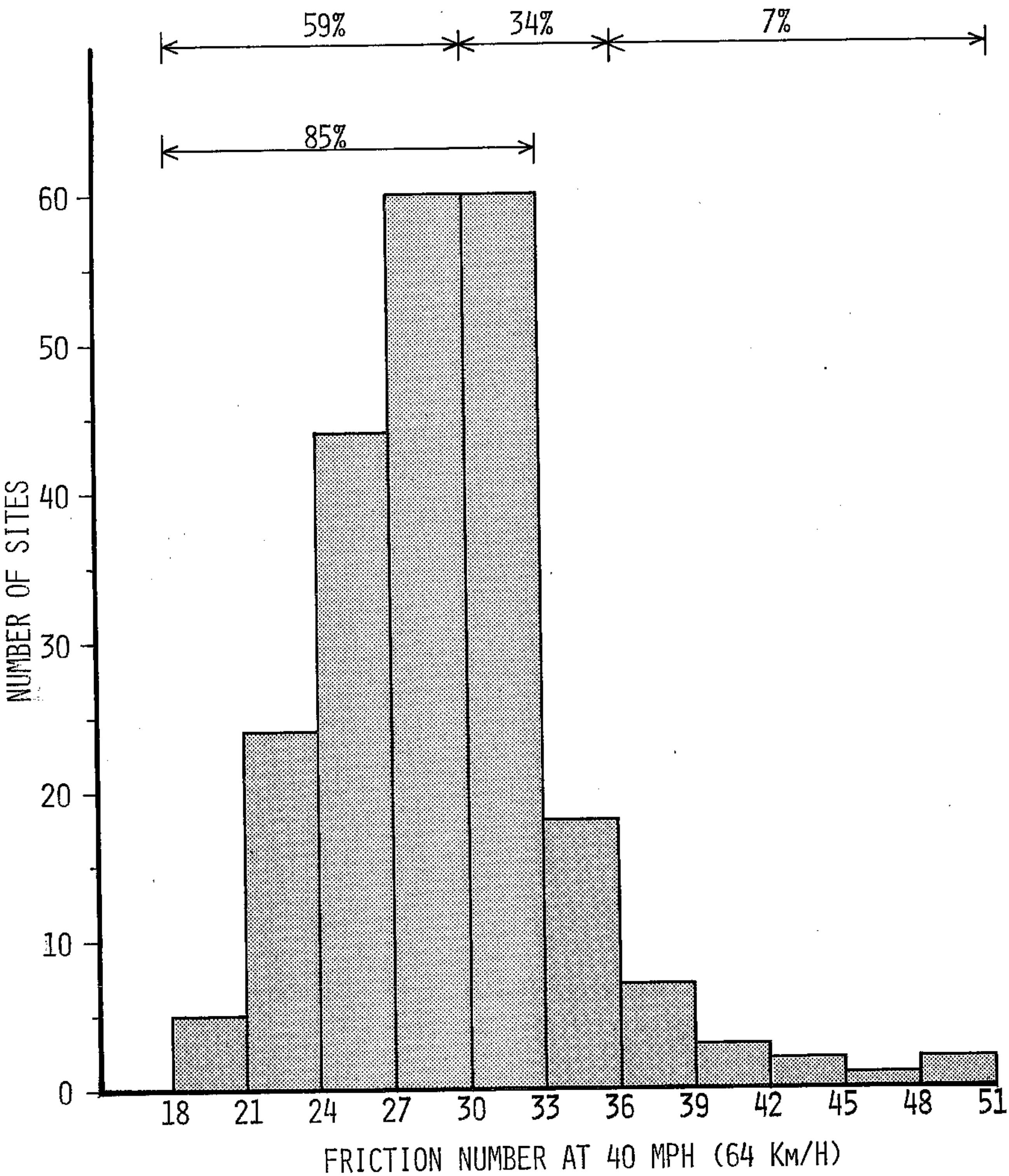

FIGURE 1. HISTOGRAM OF FRICTION NUMBER FOR 226 SITES HAVING A DISPROPORTIONATE NUMBER OF WET-PAVEMENT ACCIDENTS.

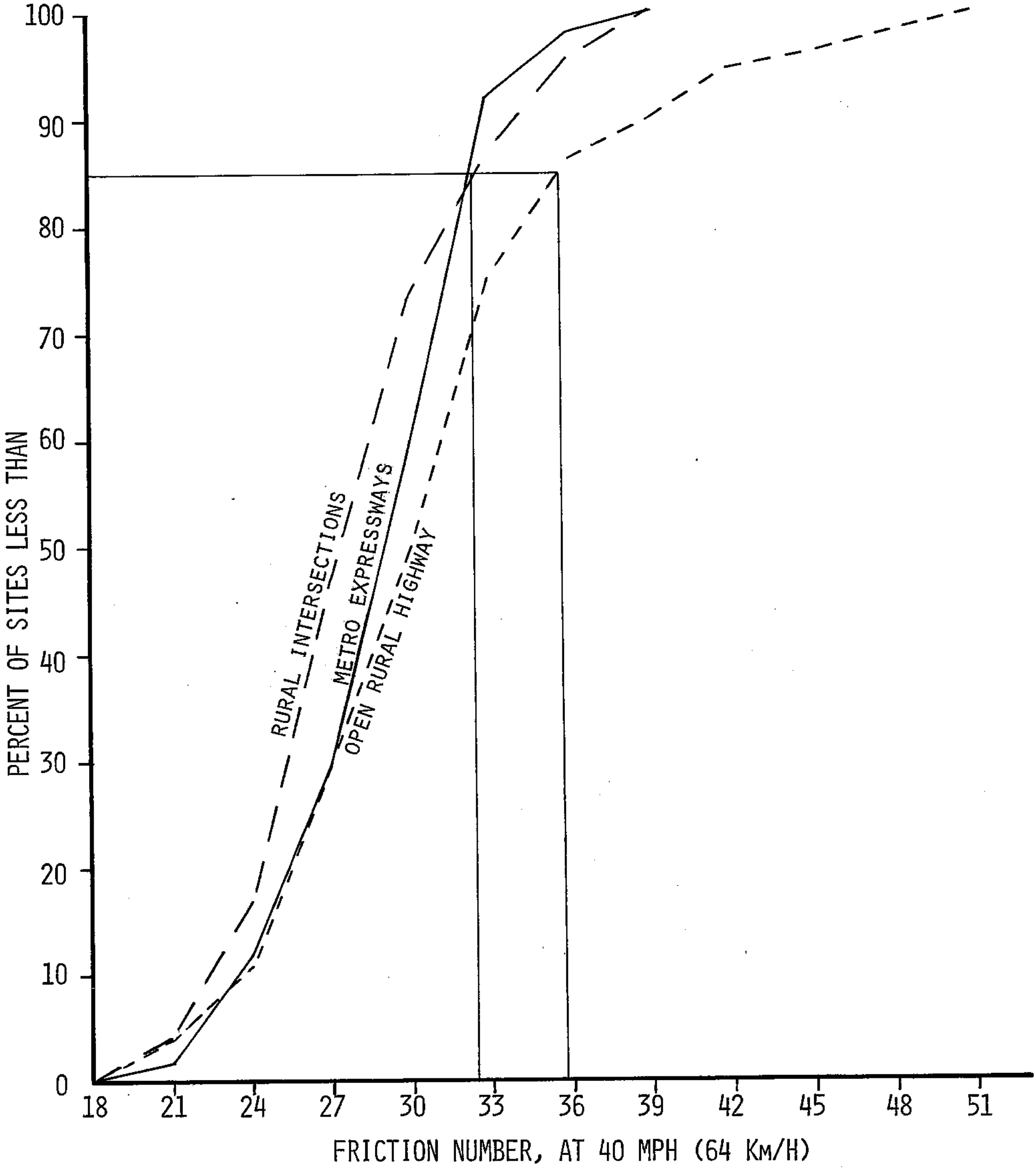

FIGURE 2. RELATIVE CUMULATIVE FREQUENCY CURVES OF FRICTION NUMBER FOR SITES WITH A DISPROPORTIONATE NUMBER OF WET-PAVEMENT ACCIDENTS.

that rural open highways, as a group, must sustain higher friction levels than metropolitan expressways and rural intersections to keep disproportionate numbers of wet-pavement accidents at the same level. The significance of this difference is unexplained by the analysis, but logically it must be related to the frictional demand unique to each accident-site grouping. Examination of the 85th percentile level (the point in Figure 1 below which a marked increase occurred) suggests that wet-pavement accidents in Illinois should decrease as the statewide pavement friction level approaches an FN of 36 for rural highways and 32 for rural intersections and for metropolitan expressways. These values support Kummer and Meyer's recommendation of adopting a tentative minimum FN_{40} of 37, which should satisfy the minimum frictional demand of a majority of motorists driving at a mean speed of 50 mph as well as reinforce FHWA's policy of participating in the cost of projects for upgrading pavement friction when the FN is below 35.

Runkle & Mahone (8), after making a critique of available tentative friction guidelines, concluded that selection of appropriate minimum friction numbers still remains a major issue among researchers. Nevertheless, for the purpose of identifying potentially hazardous wet-pavement accident sites in Virginia, they proposed an FN of 30 as a minimum guideline value for interstate and other divided highways and an FN of 40 as a minimum guideline value for two-lane highway sites. When friction numbers fall below these values, sites are not scheduled automatically for treatment, but instead they are included with sites selected from accident records for evaluation in the normal site review process of the wet-accident reduction program. Depending on the results of the review process, they may or may not be treated.

In a study of Michigan accident records at 2000 intersections, Holbrook (9) determined that surface wet time and friction number are important factors in wet-pavement accidents. Moreover, no critical friction number emerged as a point above which the wet-pavement accident hazard disappeared, but when the FN fell below 30, wet-pavement accidents intensified with declining surface friction. A seasonal change of only 4 percent in wet time, according to Holbrook, has four times more impact on wet-pavement accident incidence than does a 10-unit decline in friction number (40-30).

Climatological data in Illinois (10) indicate that as one travels from north to south, the average annual number of days with 0.25 in. (6 mm) of precipitation not only increases from 38 to 50 but also occurs more evenly from month to month. This implies that southern Illinois has a longer wet-surface time than upstate. When upgrading comparable sites having about the same pavement friction characteristics, perhaps a southern site should receive a higher priority over an upstate site because the potential for reducing wet-pavement accidents should be greater in the area having the longer wet-pavement exposure.

The skid-trap ratio concept can help a highway engineer identify a potentially slippery surface, but it does have a handicap--quick retrieval of current rainfall data for a site. Sometimes, decisions and recommendations about sites are wanted before weather summaries are published. On these occasions an estimate may be useful.

Assuming that rainfall throughout Illinois more or less follows a pattern, mean dry day-wet day ratios for April through October were calculated for each weather station statewide between 1965 and 1975 and are plotted as isolines on a map of Illinois (Figure 3). Using the mean ratios in Figure 3, a highway engineer can judge whether a pavement at a particular site may be suspected as slippery by using the following procedures:

1. For each site, determine the number of wet-pavement accidents and dry-pavement accidents from April through October for at least the past 2 or 3 years.

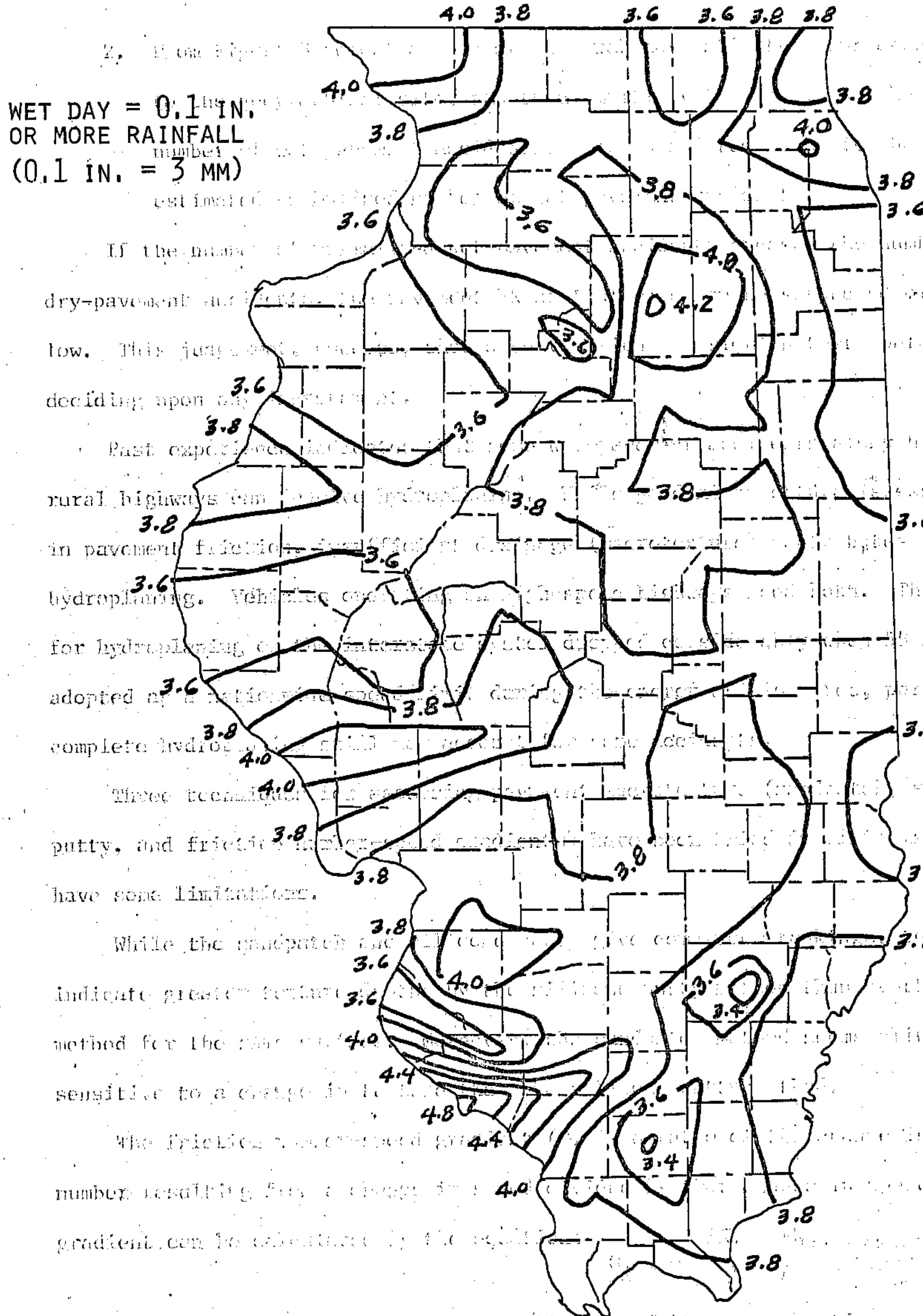

FIGURE 3. MAP OF ILLINOIS SHOWING DRY DAY-WET DAY RATIOS (APRIL-OCT. FOR 1966-75)

friction is measured. The gradient may range from 0.1 FN/mph for coarse-textured surfaces to 1.0 FN/mph for fine-textured surfaces. (2)

Although some believe that the friction number-speed gradient is more indicative of drainage (macrotexture) than either the silicone putty or the sand-patch methods, a gradient alone can be misleading. On the one hand, some Illinois surfaces exhibit steep gradients (0.6 to 1.2) which indicate that they are fine-textured surfaces when they actually contain positive drainage (macrotexture). Apparently, friction sometimes overshadows drainage in a texture until the initial friction decreases to a lower level. On the other hand, some Illinois surfaces produce flat gradients (below 0.2) which suggest they possess good drainage (macrotexture) when in fact they contain little, if any, positive drainage. This situation can happen when friction numbers are low. Worley et al. (11) noted similar findings in Kansas. When analyzing gradients, one must examine the whole territory--friction level, gradient, and surface.

Deterioration of Pavement Friction

Illinois has more than 13,000 miles (20,900 Km) of interstate and primary highways, of which one-third are portland cement concrete (PCC) while the remaining two-thirds are dense-graded bituminous concrete. Findings in Phases 2 and 3 (5) indicate that two-lane highways in Illinois can maintain good friction during their normal structural service life as long as PCC pavements are free of studded tire wear and the use of crushed limestone is restricted in Class I bituminous concrete. However, multi-lane highways, particularly those in metropolitan areas, probably will need to be upgraded for pavement friction before the end of their normal structural service life.

Pavement friction deteriorates as traffic wears and polishes a surface, but this loss often varies between, as well as within, wheelpaths. Along open highways, inner wheelpaths usually have lower friction than outer wheelpaths, but at approaches to intersections either the inner or the outer wheelpath apparently has an equal chance of having lower friction.

After several years of pavement wear, the friction number within a wheelpath can vary up to 10 friction numbers. This variation is more pronounced in pavements where high traffic densities promote narrow channeling within a wheelpath, causing a distinct transverse variation in friction, being lower at the wheelpath centerline, where the most wear occurs, and being higher away from the center of the wheelpath, where fewer applications occur (3).

Testing at the AASHO Road Test (12) demonstrated that pavement friction decreases as axle load increases, but so far, no one has developed a satisfactory method of accounting for this additional loss under mixed traffic. Nevertheless, the rate of wear and polishing can and does vary with the amount and composition of traffic as well as with the kind of materials used in the pavement.

Wear curves developed in Phase 3, for example, illustrate this loss in friction as axle applications increase. In a traffic lane, a change in friction by type of surface along open highways and at intersections can be seen respectively in Figures 4 and 5. Similar wear curves for Class B Bituminous Surfaces and for Class A Bituminous Surface Treatments can be seen respectively in Figures 6 and 7.

Besides normal long-term wear, friction fluctuates seasonally as well as daily. Daily changes are small and are caused partly by changes in temperature and partly by changes in friction (microtexture). Measurements made on cold days generally are higher than those made on hot days, and according to Willing (13), pavement temperature has a greater effect on bituminous than on portland cement concrete pavements.

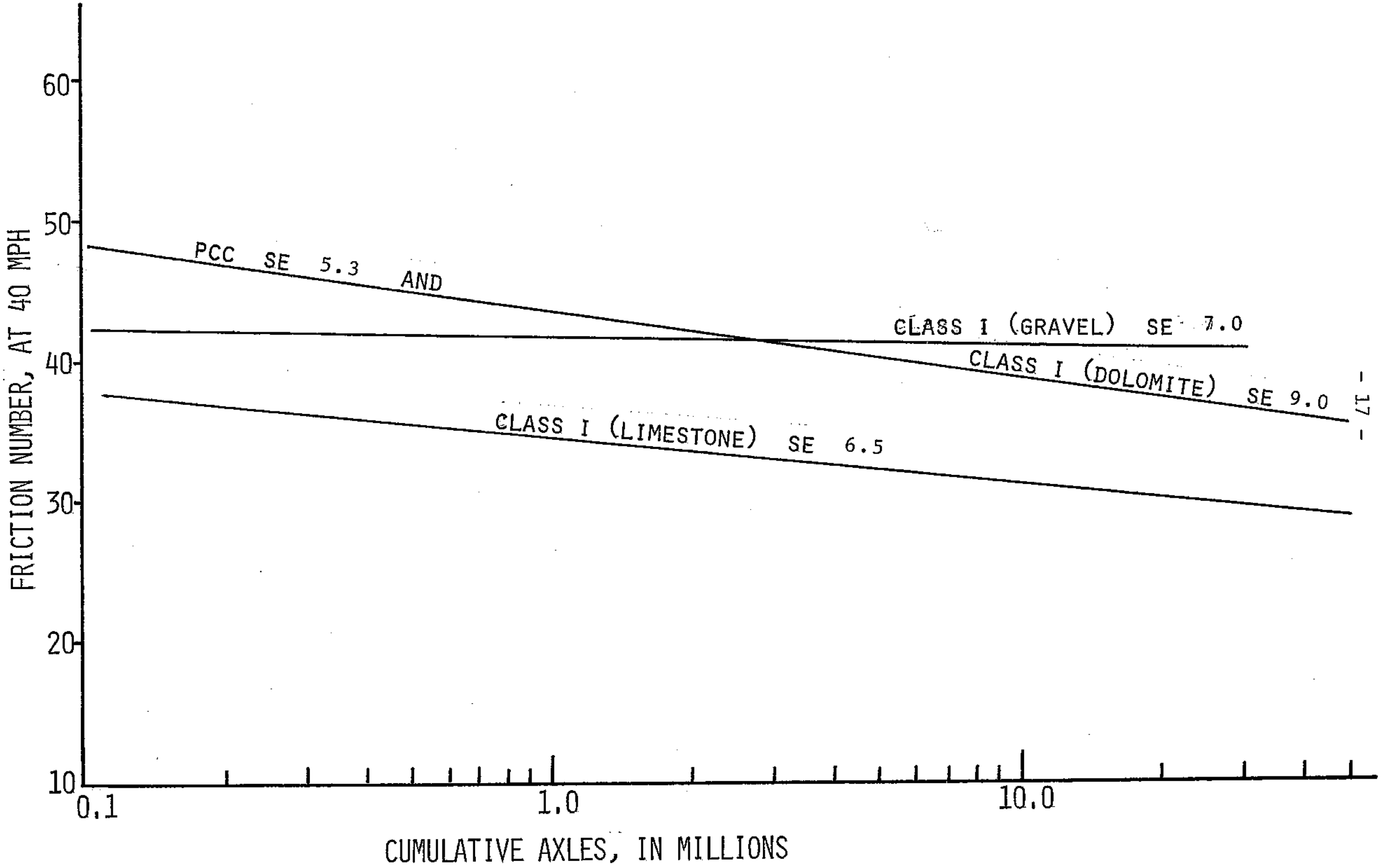

FIGURE 4. WEAR CURVES FOR TRAFFIC LANES ON OPEN HIGHWAY BY TYPE OF SURFACE.

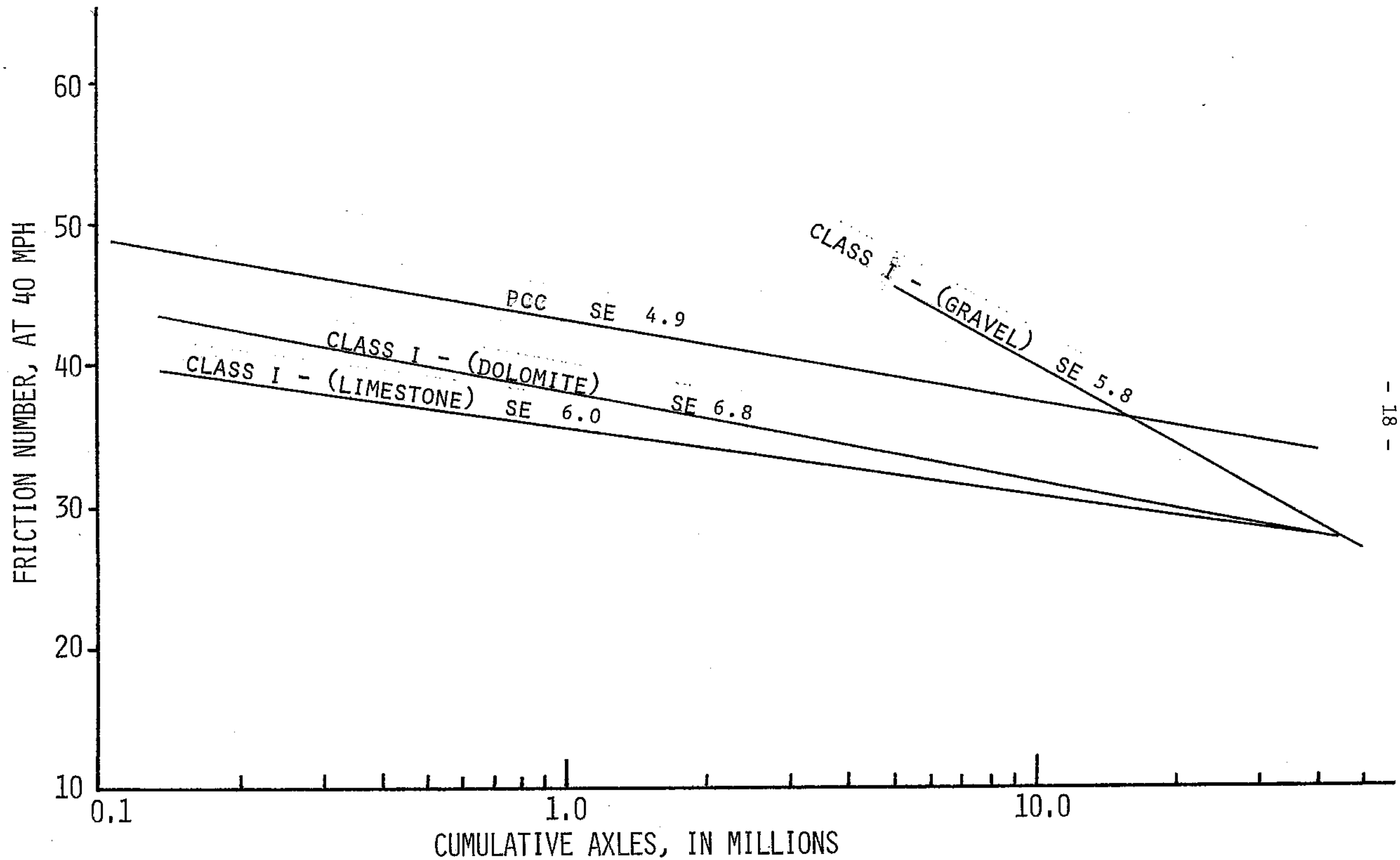

FIGURE 5. WEAR CURVES FOR TRAFFIC LANES AT INTERSECTIONS BY TYPE OF SURFACE.

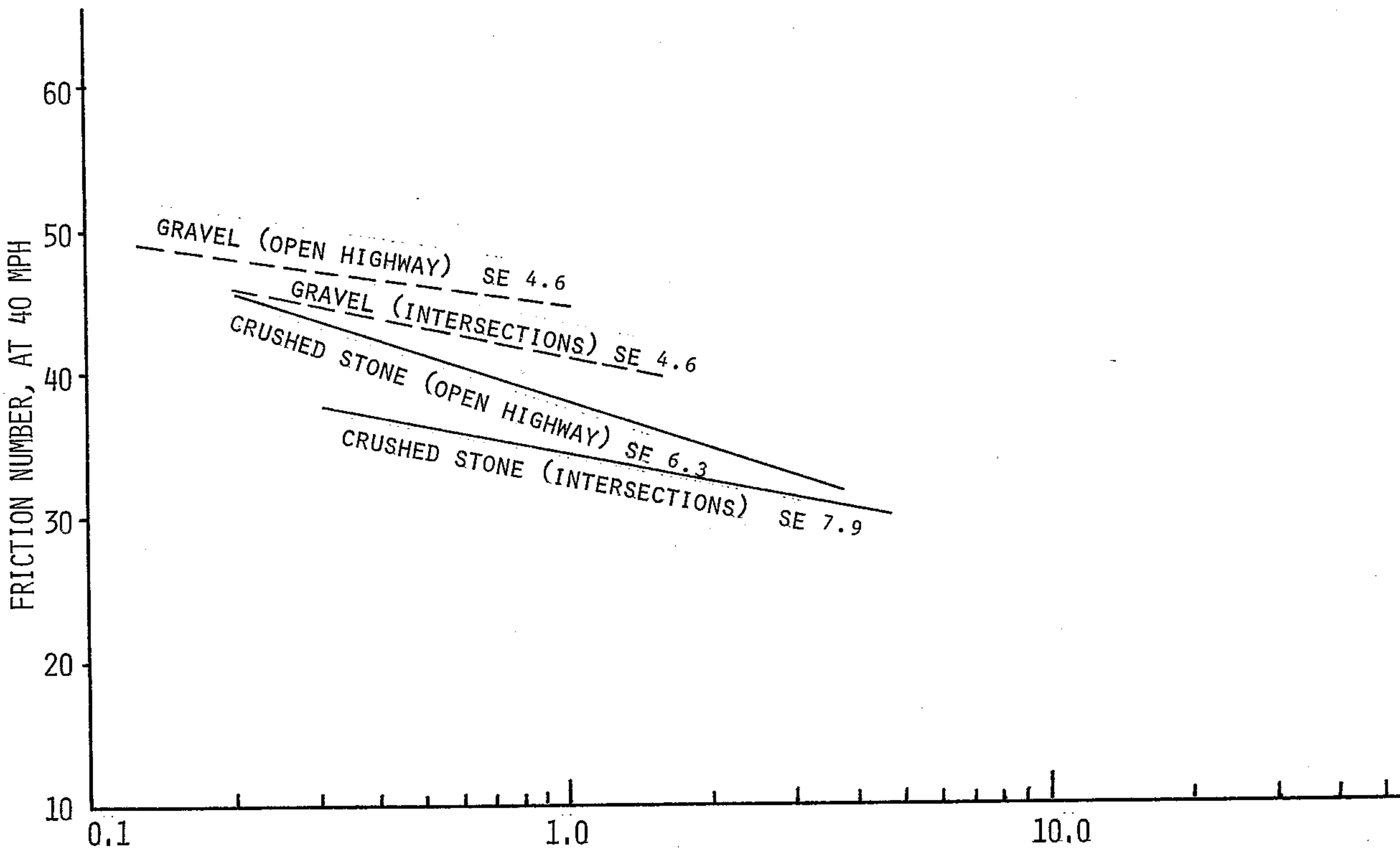

FIGURE 6. WEAR CURVES FOR CLASS B BITUMINOUS CONCRETE SURFACES BY LOCATION AND BY AGGREGATE TYPE.

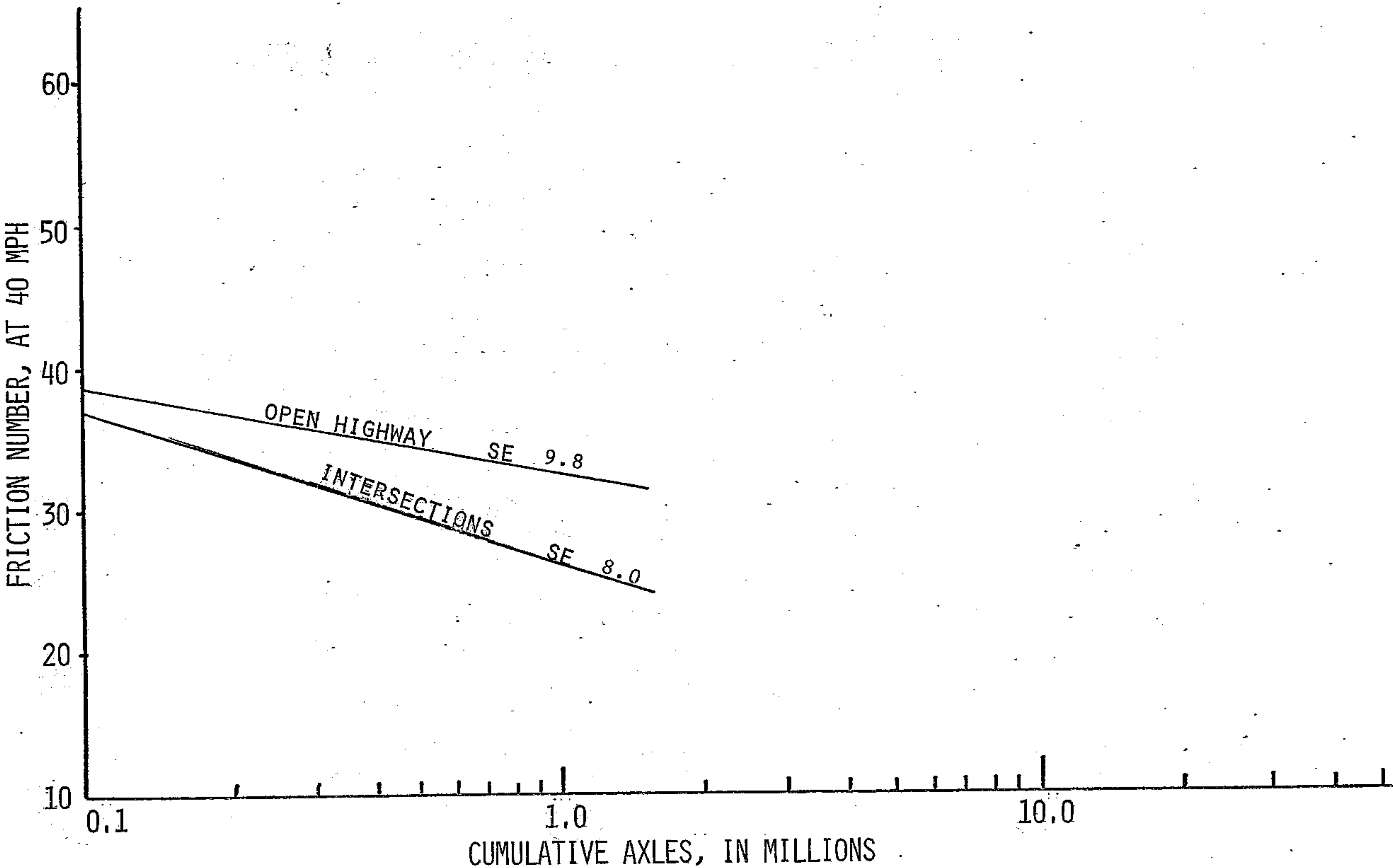

FIGURE 7. WEAR CURVES FOR CLASS A BITUMINOUS SURFACE TREATMENTS BY LOCATION.

As for microtexture, hard rainfall cleanses road film from the pavement, exposing microtexture in the aggregate. This occurrence raises friction slightly for several days until traffic lowers friction by polishing the aggregate. Rainwater containing dissolved carbon dioxide and sulfur dioxide, according to Gwen (14), attacks carbonates like limestone and dolomite and improves friction. Salt brine also affects minerals, adding roughness. This variation in friction according to Willing (13) is more pronounced in bituminous than in portland cement concrete surfaces. For reasons previously mentioned, spring pavement friction, particularly in bituminous pavements, can range from 2 to 12 friction numbers higher than those values obtained in the late fall.

When a November 1975 inventory of Chicago Expressways was compared with a repeat inventory in February 1976, mean friction increased from 7 to 12 numbers in dense-graded bituminous concrete containing dolomite and from 5 to 10 numbers in a 50-50 blend of slag and dolomite. Furthermore, the increase widened as traffic volume increased. A long bridge segment having a sandmix surface had the least variation--2 to 4 friction numbers.

In Illinois the risk of wet-pavement accidents is greater at braking sites, like intersections, railroad crossings and toll plazas; at curves, particularly where they are associated with a downhill grade; and at speed-change areas in interchanges than along a straight, level highway.

Low friction at bituminous intersections occurs because heavy slow-moving vehicles compact and rut the surface, which often causes free asphalt to migrate upward, closing surface texture in wheelpaths. This action, along with wear and polishing, reduces drainage (macrotexture) and friction (microtexture) up to 400 ft (122 m) back from the stop line. Rutting also traps water in wheelpaths and extends the time the surface is set, which adds further risk in skidding accidents.

Bleeding, another factor that contributes to a loss of friction in bituminous surfaces, usually is attributed to higher than design asphalt contents as well as to other aberrations and reduces both friction (microtexture) and drainage (macrotexture). This loss frequently leads to a smooth slippery surface.

Studded tires, since their debut in the mid-1960's until banned in 1976, unquestionably have accelerated pavement wear and have lowered surface friction in PCC pavements, particularly in northern Illinois. In PCC pavement, friction depends primarily on the surface texture created in the fresh concrete mortar. In the past a burlap drag texture has provided good initial friction but limited drainage. Yet, under heavy and moderate traffic, both can be lost soon after the pavement is opened to traffic. Recently, the specifications were changed to include transverse tining, which provides positive drainage (macrotexture). This change will be discussed later.

Contamination, another factor, can adversely affect pavement friction. While normal road film accumulation (dust, oil drippings, etc.) can lower friction slightly, heavy contamination, such as oil and other viscous materials accidently spilled on a surface, makes it hazardous. A common belief among motorists is that pavements are more slippery when light rainfall begins than it is later on during the rain. So far, no research substantiates this claim. Whether the drop in friction is real or imaginary, drivers usually continue driving on a wet surface as though it were dry until they subconsciously adjust their driving to the new conditions (3).

RECOMMENDATIONS FOR DESIGN AND CONSTRUCTION

A long-term strategy for reducing wet-pavement accidents involves upgrading as well as prolonging the friction level of pavements in Illinois. Designing, constructing, and maintaining adequate pavement friction require an understanding of the factors that influence pavement friction. For example, coasting and constant-speed driving require a low friction level for tires to grip the roadway. Cornering, on the other hand, requires about two times as much friction, and accelerating to pass, cornering and accelerating, decelerating to a full stop, and cornering and braking need a friction level three to four times higher than constant-speed driving.

Vehicle speed, another important variable, also influences pavement friction. As speed increases, friction drops, and an opportunity for hydroplaning occurs when water depth is sufficient that water cannot escape from between tire-pavement interface. At lower speeds, say below 45 mph (72 Km/h), a fine-textured surface can supply high friction, but at higher speeds, say 45 mph (72 Km/h) and above, a surface needs both friction (microtexture) and drainage (macrotexture) so that the tires can grip the surface.

Having acquired some knowledge about existing surfaces (5) and about several experimental surfaces (4), pavement friction in Illinois can be improved as new pavements are constructed and when specific roadway elements require corrective treatment.

This section focuses on several ways pavement friction can be improved and calls attention to critical details that must be monitored during construction. Recommendations for bituminous concrete pavements are made first, followed by recommendations for portland cement concrete pavements.

Dense-Graded Bituminous Concrete

In bituminous concrete, coarse aggregate type, size, shape, hardness, and mineral composition as well as the resulting texture (surface drainage) affect pavement friction. When selecting coarse aggregates, polish and wear resistance (hardness and mineral composition of an aggregate) and drainage (macrotexture) usually are the characteristics most looked for in a quality friction surface.

Findings in Illinois, reinforced by both field and laboratory studies conducted in other states (5), indicate that soft carbonate coarse aggregates, particularly limestone (CaO), rank at the bottom relative to friction quality for use in bituminous concrete. Yet, some carbonate rocks such as dolomite (MgO), usually provide better friction than limestone because they contain magnesium, which adds hardness, and silica sand impurities, which add microtexture. Research in New York (15), Virginia (16), and Pennsylvania (17) indicates carbonate aggregates require 10 to 20 percent sand-size acid-insoluble residue to maintain good friction under moderate-to-heavy traffic. Most dolomites in Illinois, however, contain less than 10 percent sand-size acid-insoluble residue, which makes dolomite less desirable under heavy traffic unless it is blended with a harder, higher-friction aggregate such as a slag.

Experience in Illinois as well as elsewhere indicates that bituminous concrete containing limestone (Moh's hardness 3) will reach a friction number in the mid-30's after one to two million vehicle passes whereas dolomite (Moh's hardness 3.5 to 4) and crushed gravel (Moh's hardness 4-5) surfaces require 40 to 50 million vehicle passes to reach the same friction level. For this reason, Illinois, like New York, Pennsylvania, and Virginia, has restricted the use of carbonate aggregates in new bituminous surface courses.

DESIGN MEMORANDUM No. 75-9 (effective May 5, 1975) refers to a special provision containing revised specifications for Class I Bituminous Surface Course mixtures having improved frictional properties. There are three surface mixture classifications: Mixtures C, D, and E. Mixture C is unchanged from the previous specification, Mixture D is the same as Mixture C, except that the use of limestone as the coarse aggregate is not permitted unless blended 50-50 with slag. Mixture E eliminates the use of limestone completely and requires coarse aggregate to be either slag or a 50-50 blend of slag and crushed dolomite or crushed gravel.

The following policy governs the use of these three mixtures:

1. Mixture C may be used as surfacing on roads and streets, except on the primary system, having a design ADT 500 or less.
2. Only Mixture D or E should be used as surfacing on secondary and local roads and streets having a design ADT greater than 500, on all two-lane primary highways, on four-lane highways having a design ADT of 25,000 or less and on six-lane or greater highways having a design ADT of 60,000 or less.
3. Only Mixture E should be used in the Chicago Metropolitan Area as surfacing on four-lane highways having a design ADT greater than 25,000 and on six-lane (or greater) highways having a design ADT greater than 60,000.

Implementing this special provision, which calls for the use of coarse aggregates in bituminous surfaces with higher quality friction characteristics, not only should improve friction (microtexture) and drainage (macrotexture) in bituminous surfaces but, over the long term, should reduce the number of skidding accidents occurring on them.

In bituminous concrete mixture design, the asphalt content normally is selected near the peak or on the downhill side of the Marshall Stability Curve. Mixture designs are based on 100 percent dry aggregates, and corresponding design asphalt contents derived from them sometimes need adjusting in the field, depending on traffic volumes and on aggregate variability.

Slag, a hard vesicular aggregate, has a low specific gravity (2.20-2.30) when compared with crushed stone (2.60-2.65), and also has higher absorption characteristics, which can vary widely within as well as among sources, than most crushed stones.

High absorptive coarse aggregates in bituminous concrete mixtures require more attention to design details and to quality control than mixtures with low absorptive aggregates to produce satisfactory mixtures with optimum asphalt contents. Required optimum asphalt contents of production mixes are more likely to vary and to deviate from design asphalt contents when slag or other absorptive coarse aggregates are used. Variability in aggregate absorption and insufficient drying of the coarse aggregate can contribute significantly to this variation. Holding the mix in a surge bin for 20 minutes, using coarse aggregate from a single source, predrying the aggregate, and extending the drying cycle are ways of reducing this variability.

When slag is blended with other coarse aggregate, it is likewise important to make sure that proper blending in accordance with the mix design is achieved. Variability in blending may not only affect the friction characteristics of the completed surface but also will create variability in optimum asphalt content as well as deviations from the design asphalt content.

When an absorptive coarse aggregate is used in a bituminous mixture, field density test results can be in error if some moisture is retained in the aggregate. Density usually is computed by Method 1:

$$"d" = \frac{A}{A-B}$$

where: A = oven dry wt
B = submerged wt

When absorptive aggregates (+2.5 percent) are used in a mixture, density should be computed by Method 2:

$$"d" = \frac{A_2}{E-C}$$

where: A_2 = oven dry wt
E = saturated surface dry wt
C = submerged wt

Before removing samples from the surface for testing, density can be checked by the nuclear method.

Open-Graded Asphalt Friction Courses

Open-graded asphalt friction courses, 1/2 in. to 3/4 in. (13 mm to 19 mm) thick, provide an economical way of upgrading surface friction of an otherwise structurally sound pavement. The main advantage of this high-void, hot-asphalt plant mix is that it permits rapid drainage of rainfall through the course, which lessens the potential for hydroplaning, especially at curves and in flat sag vertical curves. Other advantages offered by open-graded friction courses are:

- Reduced tire splash and spray
- Better visibility of pavement marking in wet weather
- Smoother and quieter ride

The open-graded asphalt friction course is basically a single-size coarse aggregate with minimum fine aggregate and high asphalt content, creating a thick asphalt film over the aggregate. Mixing temperatures normally run between 225°F (107°C) and 250°F (121°C), which is considerably lower than that for dense-graded mixes. Mixing temperatures must be kept low, and when they rise from 10°F to 15°F (6°C to 8°C) above target temperatures, excessive segregation and asphalt drainage to bottom of the truck bed during transportation can occur. This can cause fat and lean spots in the surface and can result either in poor performance or in a completely unsatisfactory job.

To anyone unfamiliar with an open-graded asphalt friction mixture, it quite likely will appear too rich. The first time inspectors and plant operators encounter this mix, they will need reassurance that a rich-looking mix is not only satisfactory but desirable.

Past experience suggests that laydown rates usually are underestimated, causing unnecessary starts and stops by the paver. Because open-graded asphalt friction courses are thin, only 3/4 in. (19 mm), paving speed can be increased considerably so long as paver chatter and surface tearing do not develop. Some contractors report handling and laydown can be improved by adding as little as 1 oz (.03 dm^3) of silicone to 5000 gal (18.9 m^3) of asphalt cement. The silicone additive, according to some observers, also tends to prevent excessive asphalt drainage in trucks.

Open-graded friction courses must be placed only in warm weather to prevent the mixture from cooling too fast. A minimum surface temperature above 60°F (16°C) is recommended. Rollers should stay close behind the paver. Usually, one or two passes at the most with a medium-weight steel-wheel tandem roller, less than 10 tons (9071 Kg), will achieve consolidation. Additional rolling, after the mix has cooled, often breaks the asphalt bond between aggregates.

To maintain internal water drainage, friction courses must be kept above shoulder surfaces in rural sections and above gutter flags in urban sections; otherwise, water will be trapped in the surface and cause deterioration during freezing weather.

Bituminous Sand Mixes

Sand mixes, like slag sand and Tapisable, have gritty textures, which provide high surface friction especially at speeds below 40 mph, (64 Km/h) but at the same time have limited drainage capabilities. Because of their high friction qualities, sand mixes can be very effective in reducing wet-pavement accidents at intersections and on urban streets where frictional demand is paramount but tire drainage (macrotexture) is important. Their use on rural interstate and primary highways is not recommended because they usually have insufficient drainage (macrotexture) to prevent hydroplaning. Nevertheless, blending fine aggregates that wear at different rates can enhance drainage (macrotexture). Blending up to 30 percent of a soft aggregate with a hard aggregate can increase drainage yet keep the friction loss to a minimum. Under traffic, the softer aggregate wears, leaving the harder aggregate protruding above it, thus creating drainage (macrotexture).

Performance of sand mixes can be extended by adding rubber compounds to the asphalt binder. This modifies the behavior of the asphalt binder as temperature changes, but at the same time it neither increases nor decreases friction significantly.

Portland Cement Concrete

Pavement friction in a portland cement concrete (PCC) pavement depends upon the fine aggregate in the textured surface mortar rather than the coarse aggregate, which is not normally an exposed part of the surface. To provide adequate surface friction, a pavement needs both friction (microtexture) and drainage (macrotexture). In concrete pavements, silica sand in the mortar supplies the friction (microtexture) while texturing the plastic concrete during final finishing furnishes the drainage (macrotexture).

Improper mix design and quality control can affect pavement friction (2). An increase in water-cement ratio and addition of water to the surface of plastic concrete during finishing accelerates wear, which reduces the benefit of the original texture. A decrease in cement content also will hasten wear. Retaining pavement friction requires quality portland cement concrete.

Texturing studies recently conducted in Illinois as well as other states (21) strongly suggest that transverse grooving in plastic concrete is an excellent method of providing the drainage (macrotexture) needed in PCC pavement. Accordingly, Illinois in 1976 issued a special provision for texturing concrete pavement which requires that the final finish be obtained by use of a carpet drag composed of artificial turf immediately followed by a mechanically operated metal-comb transverse grooving device. The comb of metal tines produces 1/8-in. grooves at 1/2-in. centers and from 1/8 in. to 3/16 in. deep by dragging the comb across the surface.

While observing texturing on several of the early projects, several conclusions were formulated. They are:

(1) The use of one machine for both texturing and applying a curing membrane is not recommended since the time the membrane is being sprayed usually conflicts with the time texturing should be done.

(2) The optimum time for texturing is when the water sheen begins to disappear.

(3) Overlapping transverse textures weakens the surface, making it more susceptible to rapid wear. Operators should avoid overlapping and should keep each succeeding pass 1/2 in. to 1 in. from the preceding pass.

(4) The comb should be pulled across the surface slow enough so that the tines penetrate the surface to the required depth yet fast enough so that grooving keeps pace with the finishing machine. When tines become short and stiff, they should be replaced.

RESTORATION OF EXISTING SURFACES

As previously mentioned, available pavement friction changes continuously, but the rate at which a surface wears and polishes depends upon the amount and the composition of traffic using a roadway. Past experience indicates that friction characteristics of roadway elements, such as intersections, railroad crossings, curves, hills, bridges, and interchange areas, often need upgrading before structural upgrading is required. Not only does maneuver demand run higher but also pavement friction deteriorates faster at these places than along a straight level roadway.

When low friction is discovered, several alternatives are:

- Lower driver maneuver demands.
- Modify existing surface.
- Apply new surface.

Under certain circumstances, lowering driver maneuver demand may be the preferred countermeasure while some other corrective action is being sought and programed. This will be discussed in a later section. This section deals with the ways friction can be improved by modifying an existing surface or by applying a new surface. Both portland cement and bituminous concrete surfaces are considered.

Modify Existing Pavements

Grooving, milling, planing, profiling, repaving, and acid etching are several methods of restoring frictional characteristics in worn pavements. Grooving, milling and profiling can be done either to portland cement or to bituminous concrete, and acid etching is limited to portland cement concrete.

Grooving is used widely today as a method of restoring lost pavement texture. Although longitudinal grooving does not appreciably add friction (5-10 FN), it does restore macrotexture (drainage) and has been very successful in reducing wet-pavement accidents on horizontal and vertical curves of interstate and primary highways as well as entrance and exit ramps (24).

Longitudinal grooving is preferred over transverse grooving primarily because traffic can use the adjacent lane while a self-propelled machine saws grooves in the other lane. At intersections, however, transverse grooving probably has an edge over longitudinal grooving and can be done with several smaller self-propelled machines.

Grooves cut in PCC pavements probably will last longer than those cut in dense-graded bituminous concrete. Under certain conditions, wheelpath grooves in dense-graded bituminous concrete may flow together and lose their effectiveness, but this occurrence is less likely in older oxidized surfaces than in newer surfaces.

According to the American Concrete Paving Association (23) grooves should be sawed from 0.08 in. to 0.11 in. (2 mm to 3 mm) wide and spaced at 3/4-in. centers. They should be cut not less than 1/8 in. (3 mm) nor more than 1/4 in. (6 mm) deep. Residue from grooving should be removed from the pavement before it is dissipated by action of traffic or wind.

When pavement rutting creates hazardous wet-weather driving, surface profiling or milling not only will restore pavement cross section and profile but also can improve pavement friction. This technique may defer resurfacing 5 or more years, depending on the amount of truck volume.

Because milling reduces thickness, a pavement's structural service life may be shortened, depending on how many heavy trucks it carries.

A new machine, the Roto-Mill Profiler, shows promise in restoring smoothness, friction, and drainage.

The residue from milling PCC pavements can be applied to shoulders while that from bituminous pavements can be recycled as base and subbase material. Isolated fat spots in bituminous surfaces can be removed with heater planers.

The equipment heats and scarifies the top part of the surface and, then, cuts away excess material. Sand usually is spread on and rolled into the surface while it is still hot.

The milling machine previously mentioned also can remove all or part of an existing surface and can recycle it with additional asphalt to form a new surface. Frequently a precoated high-friction aggregate is sprinkled on the surface prior to rolling to improve the surface's frictional characteristics.

Acid etching sometimes is used to roughen PCC surfaces whose aggregates will react with acid, but the benefits from etching usually are rather short-lived. Most treatments lose their effectiveness within 6 months.

Resurface Existing Pavement

The most common method of upgrading pavement friction in Illinois involves resurfacing the existing pavement surface. Open-graded asphalt friction courses, sand mixtures, and dense-graded bituminous concrete mixtures can restore surface friction characteristics.

Open-graded asphalt friction courses are suitable for rural intersections and roadways as long as the aggregates used in them have high frictional qualities. The use of limestone is not recommended. Open-graded friction courses offer potential in reducing hydroplaning on rural highways, especially at horizontal and vertical curves. Because open-graded asphalt friction courses are susceptible to oil and gas drippings, they are less desirable in parking areas and on streets with slow-moving traffic (25). Normally their service life, depending on traffic volume, can be expected to range from 5 to 10 years. Sometimes, drainage can be impaired as debris infiltrates and clogs voids and as consolidation occurs in wheelpaths. Obviously, this will reduce its antihydroplaning properties. When a structurally sound pavement contains depressions that trap water and surface distortions, they can be eliminated either by milling the surface or by placing a machine leveling course. When the milling method is used, do not place the open-graded friction course in a trench where its internal drainage is blocked by a paved shoulder or by a gutter flag.

Sand mixtures are appropriate in urban streets and at approaches to urban and rural stop intersections where frictional requirements are high but drainage (macrotexture) is less important. Because sand mixes have limited drainage (macrotexture), they should be restricted to places where operating speeds are low, say below 45 mph (72 Km/h), or to secondary roads carrying light traffic, say below 500 ADT. Depending on the traffic volume, a service life up to 5 years can be expected.

Dense-graded Bituminous Surface Courses are suitable as an overlay when both frictional and structural upgrading are indicated. Service life ranges from 10 to 15 years. Because frictional characteristics depend primarily on the type and the size of coarse aggregate, only Mixture E should be considered at places where maneuver demands require high friction characteristics. Better drainage (macrotexture) is achieved when the top size of aggregate gradation is 1/2 in. to 5/8 in. (13 mm to 16 mm). Optimum drainage (macrotexture) occurs when hard coarse aggregates are combined with fine aggregates that wear at distinctly different rates.

LOWERING FRICTIONAL DEMAND

Sometimes, changing driver maneuver demand is the only effective way to reduce wet-pavement accidents. Lowering the national speed limit to 55 mph (89 Km/h) from 70 mph (113 Km/h) on interstate and from 65 mph (105 Km/h) on primary highways in Illinois is an example of lowering demand. Lowering the speed limit not only has helped conserve fuel but also has helped reduce accidents nationwide. Narrowing the pace between faster and slower drivers has reduced frictional demand, particularly along interstate highways. Kummer & Meyer recommend a tentative minimum FN_{40} of 39 when the mean traffic speed is 55 mph (89 Km/h) and an FN_{40} of 46 when the mean traffic speed is 70 mph (113 Km/h). This theoretical 15 mph (24 Km/h) reduction reflects a corresponding drop of seven numbers in frictional demand. Perhaps lowering the speed limit along the interstate has and will continue to reduce wet-pavement accidents, especially at curves and grades.

In addition to lowering speed limits, driver maneuver demand sometimes can be lowered by either changing or modifying traffic control devices, by improving signing, by eliminating parking, and by altering pavement markings, all of which can smooth traffic flow, which in turn lowers demand. Removing roadside hazards, lengthening sight distance, flattening grades, increasing the radius of curvature and superelevation of curves to fit actual operating speeds as well as preventing water from accumulating on the pavement, are several other ways frictional demand can be lowered. Frequently, lowering driver maneuver demand is only an interim solution to reducing wet-weather accidents while a more costly permanent solution is being conceived and programed.

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