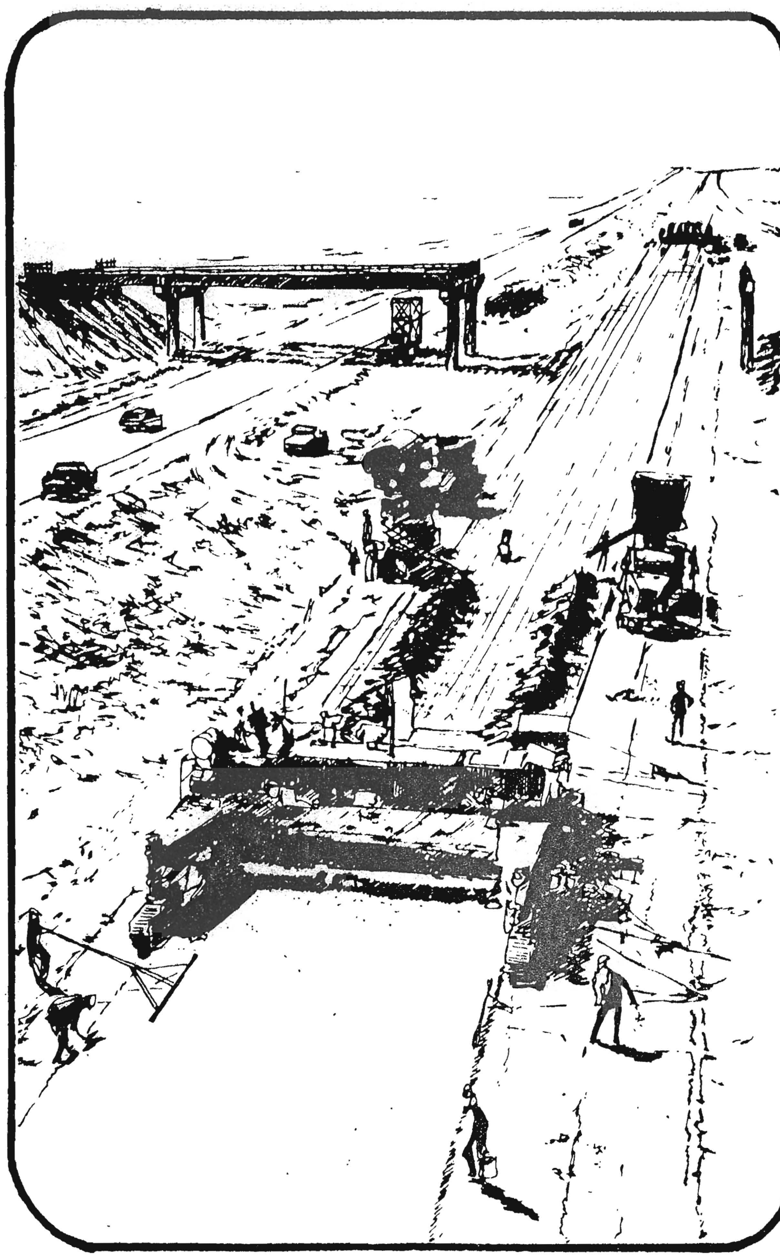
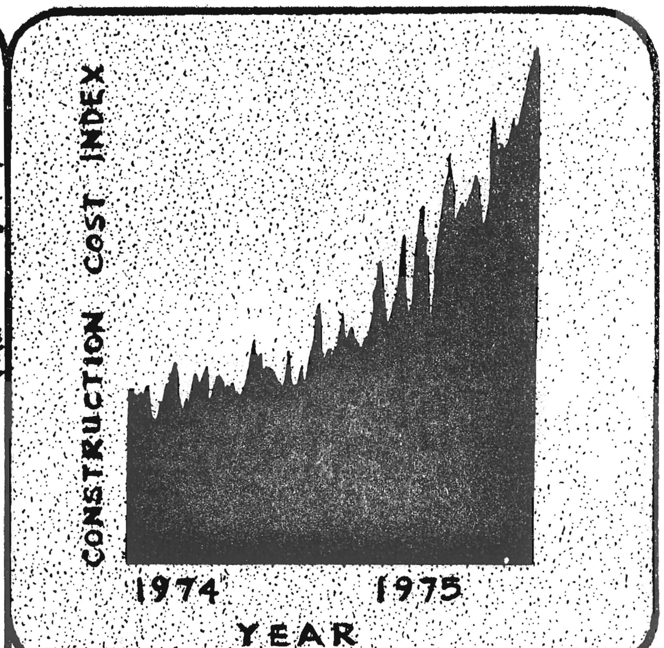
ENGINEERING ECONOMY AND ENERGY CONSIDERATIONS

SKID RESISTANT SURFACES

RESEARCH REPORT 214-7





COOPERATIVE RESEARCH PROJECT
2-9-74-214

"ENGINEERING, ECONOMY AND ENERGY CONSIDERATIONS IN DESIGN, CONSTRUCTION AND MATERIALS"

STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

AND

TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY

DECEMBER, 1975

TEXAS HIGHWAY DEPARTMENT TASK FORCE
ON ENGINEERING, ECONOMY, AND ENERGY CONSIDERATIONS

Larry G. Walker, Task Force Chairman and Materials and Tests Engineer

Charles H. Hughes, Sr., Study Contact Representative and Assistant Materials and Tests Engineer

H.L. Arno, Engineer, Secondary Roads

Paul H. Coleman, District Engineer

Wayne Henneberger, Bridge Engineer

Robert L. Lewis, Chief Engineer, Highway Design

Archie J. Sherrod, Chief Engineer, Maintenance and Operations

J.R. Stone, District Engineer

William V. Ward, Urban Project Engineer-Manager

Phillip L. Wilson, Engineer-Director, Planning and Research

Franklin C. Young, District Engineer

Theodore E. Ziller, Construction Engineer

TEXAS TRANSPORTATION INSTITUTE

W. Frank McFarland, Study Supervisor and Transportation Economics Program Manager

Jon Epps, Natural Materials Program Manager

Ronald Holder, Transportation Operations Program Manager

SKID RESISTANT SURFACES

By

Merritt M. Davis

and

Jon A. Epps

Introduction

As our road systems have improved, accident rates have decreased. Nevertheless, the total number of traffic fatalities per unit of population has remained more or less constant so that the annual number of fatalities has continued to increase. As accident data have become more refined, it has become evident that wet-road accident rates are higher than dry-road rates. It has further become evident that some locations have very high wet-road rates, and generally, these locations have been identified as having low wet-road friction.

Polishing of aggregate as a factor in low wet-road friction has been recognized for many years. However, when traffic volumes were light, attrition of material often removed individual aggregate particles before they became highly polished. Then, low wet-road friction was usually associated with design or construction faults causing fat spots by over-asphalting in bituminous pavements or lack of surface texture in concrete pavements. Such is no longer the case. Higher traffic volumes and speeds have placed higher friction demand upon our road systems; while at the same time, they cause greater wear so that friction is reduced by polishing of the aggregates used in surfacing.

Hence, a new parameter has been introduced into pavement design. That is the production of surfaces that will not only have a high initial friction but also will maintain a satisfactory level of friction throughout the structural design life of the surface. The factors leading to a control problem are illustrated graphically in Figure 59 of N.C.H.R.P. Synthesis of Highway Practice 14 "Skid Resistance" (1).

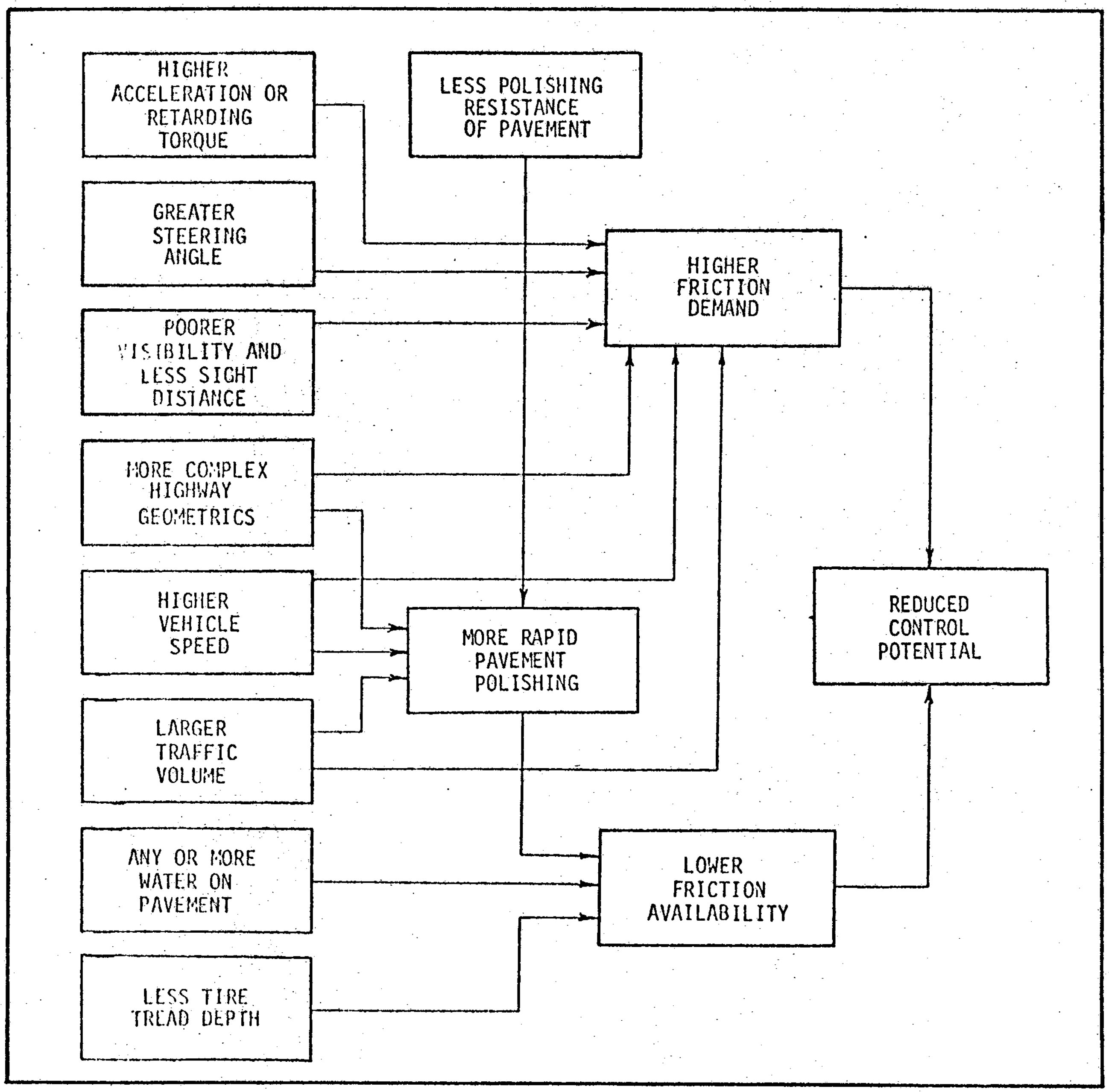


Figure 1. Factors reducing ability of driver to maintain safe level of control over his vehicle.

Not only must new surfaces be produced to have and maintain high friction, but existing surfaces identified as slippery must be improved. Consideration of appropriate materials is common both to building new surfaces and to improving existing surfaces by overlay. Some existing slippery surfaces may be treated by methods other than overlaying.

The purpose of this report is to delineate the alternatives available to the engineer to correct slippery pavements and to discuss the alternatives available to construct a pavement with high initial and prolonged skid number.

Improving Existing Surfaces

Whether on Portland cement concrete or bitumnious pavement, the repair of slippery conditions may be effected by either treating the surface or by overlaying it (Figure 2).

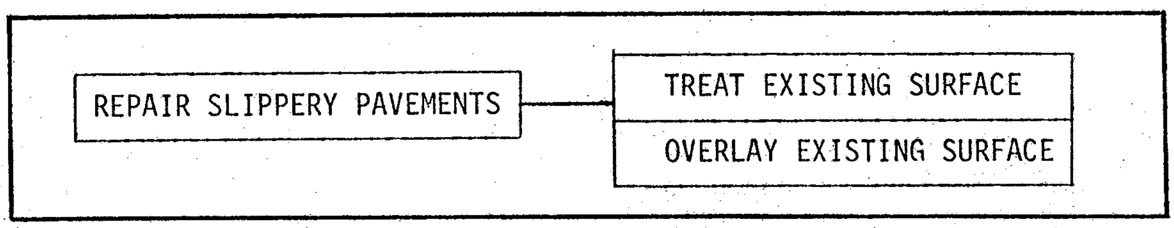


Figure 2. Fundamental approach to repair of surface pavements.

In order to develop further the above treatments, we shall deal separately with Portland cement concrete and bituminous surfaces.

Portland Cement Concrete

The following discussion of different ways to improve Portland cement concrete surfaces is divided into two sections: (1) treat existing surfaces, and (2) overlays.

Treat Existing Surfaces

The potential treatments for existing Portland cement concrete surfaces are shown in Figure 3 and Table 1.

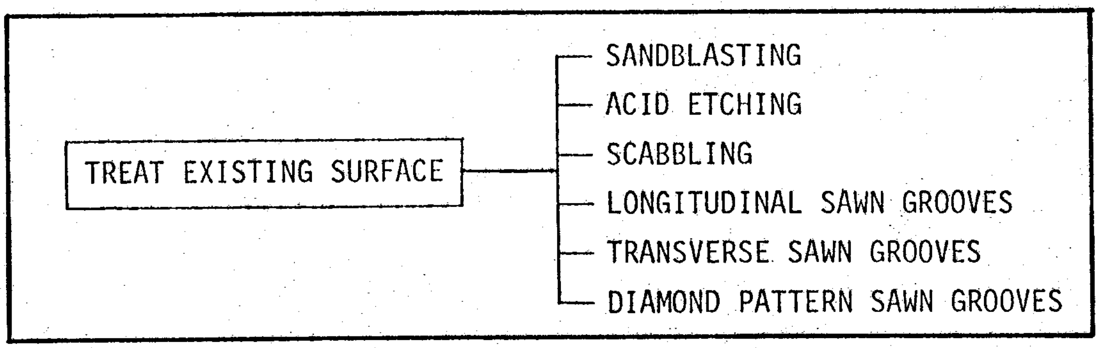


Figure 3. Rigid pavement treatments.

Sandblasting - Little is added to the available friction and the benefit is of short duration. Not recommended.

Acid Etching - Etching is effective only if mineral aggregates are reactive with the acid. It provides a temporary, limited improvement. Not recommended.

Scabbling - This is a minor roughening of the surface by an impact tool. The benefits are minor. Not recommended.

Longitudinal Sawn Grooves - Grooves 1/8" by 1/8" at 3/4" or 1" centers are sawn longitudinally in the pavement with diamond saws. The measured locked-wheel skid numbers (SN_{40}) are only slightly and temporarily improved but Farnsworth (2) reports that wet-pavement accidents have been reduced 85 percent on grooving projects in California. Longitudinal grooving is effective in reducing hydroplaning and directional-control skids; therefore, it is effective on high-speed roads, on curves and ramps and where crosswinds may be a contributing factor to lateral skids. The treatment should be used where the Portland cement concrete pavements are structurally sound and smooth riding. It is not effective for improved braking at say, a traffic signal. The effective life is 4-7 years and the cost $1/yd^2. Recommended.

Transverse Sawn Grooves - This type of grooving has not been widely used in highway pavements because they are assumed to be objectionably noisy and might create harmonic vibration in the vehicles if spacings are greater than those commonly used for longitudinal grooving. These objections may be overcome by random spacing of the grooves. Transverse grooves could prove effective in improving drainage beneath tires in the flat areas of sag vertical curves and the flat area of transition from crowned tangent to superelevated horizontal curves. The cost will be higher than for longitudinal grooving and is estimated at $1.50/yd^2. Recommended for trial.

Diamond Pattern Sawn Grooves - The concept is to provide, without objectionable noise, both lateral and longitudinal friction improvement by sawing two grooves at 45° to the road direction. Presumably the groove spacing could be increased to 2 inches to avoid small blocks subject to spalling. The treatment would materially improve drainage at sags and the flat areas of superelevation transition. Estimated cost is $2.00/yd^2. Recommended for trial.

Overlays

Overlays for Portland cement concrete surfaces offer a variety of options. To some extent the choice of treatment will be dependent upon whether improved friction is the sole requirement or whether additional structural strength, improved riding quality or other benefits are desired. Also, the expected functional life must be considered. A costly treatment that will outlast the functional life of the roadway is not justified. The potential overlay treatments are shown in Figure 4 and Table 1.

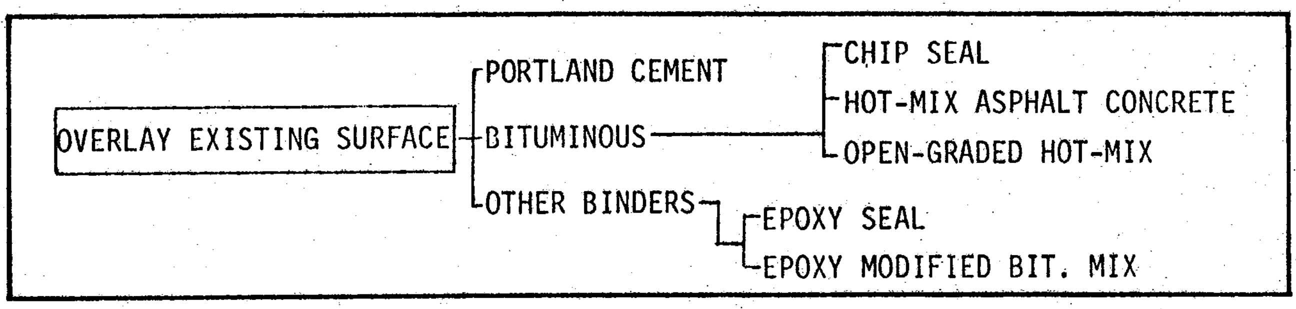


Figure 4. Overlay treatments for rigid pavements.

Portland Cement Concrete Overlay - Portland cement concrete overlay would not normally be used for the sole purpose of treating slipperiness. Thin bonded concrete patches have been used successfully to repair spalled or otherwise damaged concrete, usually in limited areas such as bridge decks. Often special additives are used to insure bond. Thicker bonded or unbonded Portland cement concrete overlays have been used more commonly to strenthen Portland cement concrete pavements on airport runways than on highways. Portland cement concrete overlays require closing of the facility to traffic while the new surface cures. The treatment is not recommended solely as an anti-skid treatment.

Chip Seals - Bituminous chip seals may be laid over concrete pavements. Properly constructed chip seals with selected aggregate provide good friction with desirable friction-speed gradients. They are subject to loss of cover aggregate where very high tire to road forces are transmitted, such as at intersections, sharp curves, or steep ramps. The friction can be dangerously low when the aggregate cover is lost. The life may be from 2-5 years, perhaps extended 2 years with rubberized asphalt. Costs would average 35¢/yd^2 for bituminous binder seals and 45¢/yd^2 for the rubberized bituminous binder. The treatment is not recommended except where the finite functional life of the road dictates the most economical temporary treatment. The treatment would require road (or lane) closings for a period of 6-8 hours, which might be awkward for a heavily-traveled roadway. In cooler climates, where cut-back asphalts are used, the period of road closing could extend to 24 hours or longer.

Hot-Mix Asphalt Concrete - This offers a good long-term solution and, at the same time, can also bolster structural strength and renew riding quality. It is a logical selection for roadways expected to stay in service for extended life. Proper care in mixture grading produces a surface texture having adequate wet-road friction and a low friction-speed gradient. The coarse aggregate can be selected to maintain good friction for the service life,depending upon the traffic intensity. Cost would be $1.50/yd^2$ and up for minimum thickness,depending upon availability and haul of the high-friction aggregate. The expected life would be 15 years. It should be noted, however, that reflection cracking will occur through thin asphalt concrete overlays which may shorten the expected life of the facility. Seal coats and open graded plant mix seals are somewhat less susceptible to reflection cracking.

Asphaltic Concrete with Precoated Chips - A modification of the usual hot-mix, dense-graded pavement is one with precoated chips of anti-skid aggregate such as lightweight aggregate or other non-polishing aggregate sprinkled on the hot-mix and rolled in. The treatment is most economical where anti-skid aggregates are long distances from the job site and overlay thicknesses are greater than about 1 inch. A recommended treatment for high-speed high-volume roadways.

Open-Graded Hot-Mix - Open-graded plant mix friction courses are made with small coarse aggregate and a minimum of fines to produce a high-void mix. The open texture provides excellent high-speed water escape to prevent hydroplaning, and the specially-selected aggregate provides high friction. The mix is not as durable as a dense-graded mix and life expectancy is 10 years; but because it is usually laid thinner, the unit cost is lower than for a dense-graded mix, probably \$1.20 to \$1.50/yd^2. Because it is laid in thin lifts, it may be used with minor or no adjustment to catchbasins and other roadway appertinences. The loss in overhead clearance is minimum. A recommended treatment.

Epoxy Seal - This surface is made by spraying an epoxy binder on the concrete and covering with a single-sized aggregate selected for angularity, resistance to polishing, surface roughness and wear resistance. It is used mainly on bridge decks where there is a restriction on the added dead load permissible. Both the binder and the aggregate are expensive. In this treatment, current construction practice involves considerable wasting of cover aggregate. The cost may be as high as \$10/yd^2 and the life probably averages 10 years. While the epoxy seal is an excellent treatment, its cost generally limits it to use on bridge decks. Recommended treatment.

Epoxy-Modified Hot-Mix - Bituminous binders may be modified by the addition of epoxies to produce stronger, more durable binders; however, the cost may be increased five to tenfold. The life of the mix should be extended--perhaps doubled; therefore, the cost might be justified if non-skid aggregate of long life is part of the hot-mix.

An appropriate use would appear to be in the open-graded, hot-mix surfacings where the advantages of good texture, high friction and thin overlay could be combined with long life. It could make possible continuity of treatment at grade and over structures on freeways if the anti-skid aggregate were lightweight. The cost would be \$5.00 to \$10.00/yd^2 and this could be justified on high-speed, high-volume, structurally sound facilities. Recommended for trial.

Bituminous Pavements

Since overlays for bituminous surfaces are essentially the same as overlays for rigid pavements previously discussed, differing only in the preparations of the existing surfaces to receive the overlays, the following discussion only covers treatments for existing surfaces. The treatments for bituminous pavements are shown in Figure 5 and Table 2 and are discussed below.

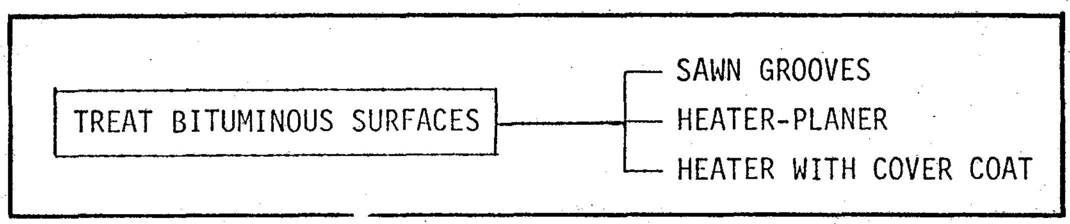


Figure 5. Treatments for bituminous pavements.

<u>Longitudinal and Transverse Grooves</u> - While bituminous pavements may be grooved by diamond saws, it may be a short-term benefit. If the binder is soft, the grooves may close by displacement; if it is brittle, the pavement may ravel at the cuts. Bituminous pavement grooving has been performed in Districts 2 and 15 with success. These pavement sections should be monitored. Recommended only on an experimental basis.

<u>Heater-Planer</u> - As an isolated spot treatment, the heater-planer may be used to treat isolated fat spots. Excess asphalt, migrated to the surface, is softened and removed by a planer, patrol grader or hand tools.

Friction is improved by exposure of aggregate in the underlying mat. Limited improvement and limited life are expected. This operation may be used in conjunction with a seal coat or thin overlay.

Heater with Cover Aggregate - When a fat surface has developed over wide areas due to overasphalting, penetration of aggregate into a soft substrate or loss of cover aggregate, it may be treated by softening with heat and applying a new cover. The heating must be carefully done so as to soften the binder sufficiently to allow embedment of the cover and to promote adhesion but not to the degree that it causes damage to the binder. The cover aggregate should be lightly pre-coated with bitumen or kerosene to promote adhesion. The treatment should not be applied to heavy-traffic roads. The estimated life is five years and the cost $\$1/yd^2$. Recommended for trial.

Material Selection for Skid Resistance

As mentioned above, a need exists to select appropriate materials to provide both good immediate and long-term friction. The immediate friction may be provided by appropriate selection of aggregate grade, surface texture, shape and proper construction control. The long-term maintenance of high friction is dependent primarily on the aggregate characteristics. A minimum polish value requirement is often utilized to specify these desirable aggregates.

Kummer and Meyer (3) have demonstrated the need for both macro- and micro-texture in surfaces to provide adequate friction over the range of normal driving speeds. Figure 6 is reproduced from their research to illustrate this requirement.

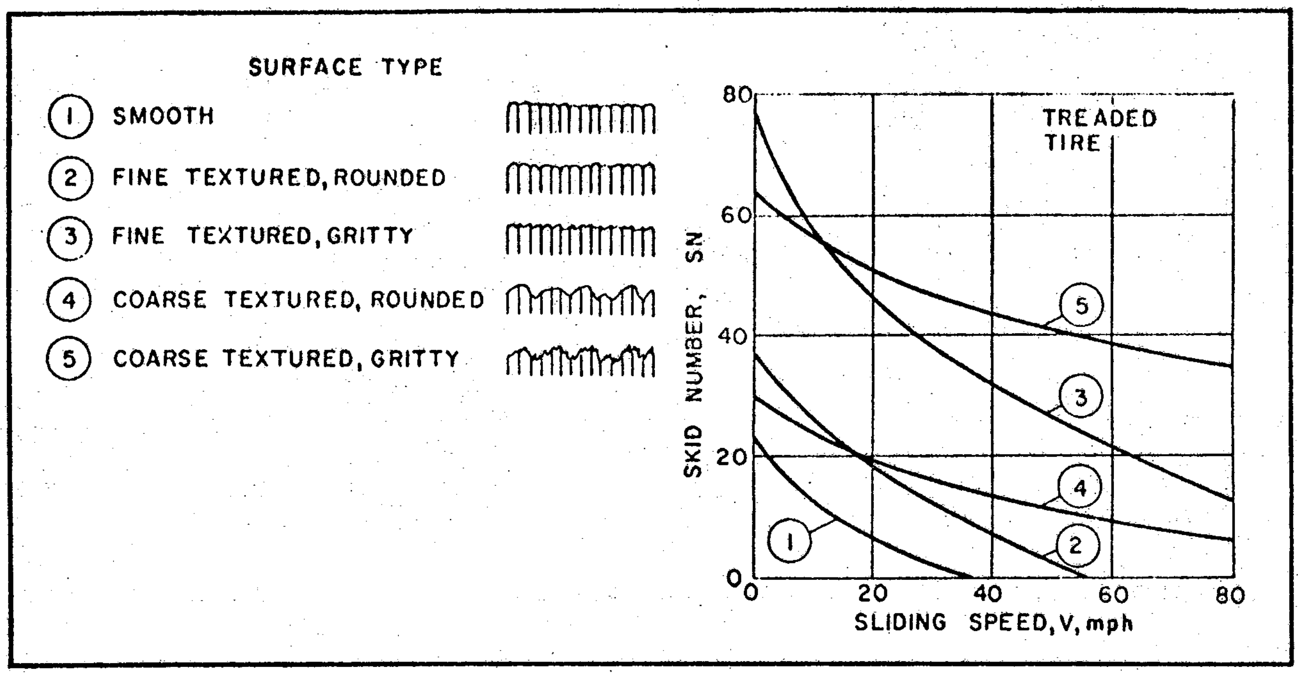


Figure 6. Road surface types and associated frictional characteristics at different speeds.

On wet roads the coarse texture or macrotexture is needed, particularly at high speed, to allow rapid escape of water from beneath tires and also to input to the hysteresis component of friction. The fine gritty texture or microtexture is needed to produce sharp high-pressure points to puncture the moisture film and promote adhesion.

In Portland cement concrete the macrotexture is provided by the finishing operation. The mortar on the surface is textured by burlap drag, by broom or other means. The microtexture is provided by the fine aggregate in the concrete. Therefore, in Portland cement concrete, the strength and durability of the surface mortar and the polishing characteristics of the fine aggregate control long-term friction characteristics.

In bituminous pavements, the macrotexture is provided by selection of the size, grading and angularity of the aggregate. As wear takes place, the fine portion is lost, exposing the coarse aggregate. Therefore, in bituminous pavements the microtexture and wear characteristics of the coarse aggregate are primary factors contributing to the long-term friction characteristics.

Gallaway and Epps (4) discussed the desirable aggregates under a number of headings which will be used here. Gallaway (5) also has an excellent discussion of materials that are suitable for producing prolonged skid resistance. Figure 7 is reproduced from Gallaway's paper.

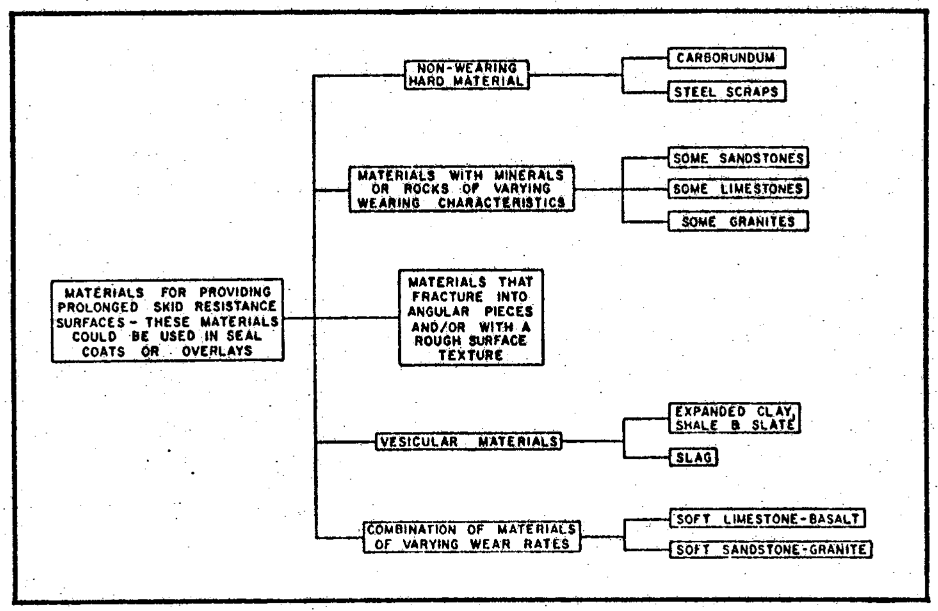


Figure 7. Materials for providing prolonged skid resistance (5).

Hard High Friction Particles

Particles with adequate microtexture and resistant to polishing in road wear may be found or manufactured. The one currently in use is calcined bauxite. Natural deposits of corundum rock may be found. Especially tailored calcined materials may be possible.

Surface Renewal by Differential Rates of Wear

Mixtures of aggregates that wear at differential rates maintain high friction by attrition of material before the harder materials polish. Such materials may be available naturally in mixed gravels; more likely, they would have to be produced by blending two or more aggregates.

Surface Renewal by Granulation

Typical of this type of aggregate is sandstone, whose hard particles are bonded by a weaker cementing matrix. The individual hard particles are dislodged by traffic before polishing. These materials are often water-susceptible and require special treatment in bituminous pavements. In very heavy traffic the rate of attrition could develop sufficient wheel-path depression to cause poor drainage and require surface renewal.

Surface Renewal by Dispersion of Hard Particles in Soft Matrix

The most common source of this type is impure limestones containing discrete hard particules in the softer limestone matrix. Laboratory tests have been developed to identify the non-polishing limestones and experience has proven their suitability in road surfaces.

Surface Renewal by Wear of Vesicular Aggregates

These aggregates maintain microtexture as wear exposes internal pores creating discontinuities and sharp edges in their surfaces. They have a proven record of performance. Techniques for pavement designs using these lightweight materials were established by Gallaway and Hargett (6).

Anti-Skid Pavement Mixtures

Fundamentally, production of anti-skid new pavements involves two items. The first is to create an appropriate macro and micro surface texture; the second is to select the materials and mixtures so that adequate texture will be maintained throughout the design life of the surface. The second requirement is, of course, dependent upon traffic and environment among other factors. For many low traffic volume roads, polishing of aggregate will not be a problem as environmental factors may be such that polishing due to traffic will not dominate. For higher traffic volumes, materials must be selected to maintain the anti-skid quality of the surface.

Portland Cement Concrete

As was pointed out in an earlier section, the friction characteristics of Portland cement concrete are largely dependent upon producing an adequate texture on the surface that will last for the life of the roadway. It seems obvious, since the texturing is done in the mortar portion of the concrete, that the mortar is most important. To produce the required qualities, mix design, construction operations, texturing, curing, and materials are all important. These will be discussed separately.

Mix Design

In order to produce the high-quality mortar surface, a low water-cement ratio must be maintained. Therefore, rich mixes that are workable but of low slump are desirable. Durability of the surface will be lost if the mix is not well compacted; but it will also be lost if too much water must be added to make the mix workable, thus increasing water-cement ratio.

Admixtures may be used to increase the workability of the concrete in order to maintain low water-cement ratio and prevent bleeding during finishing.

Construction Operations

The construction must be carried out when temperature, wind and humidity conditions are such that the concrete will not be robbed of its water for hydration. The finishing methods must be such as to achieve the proper surface without producing structurally weak laitance on the surface.

Texturing

The high-speed drainage of water from beneath tires depends upon an adequate macrotexture. With the high speeds of modern road geometrics and vehicles, the required texture depth is greater than that produced by some traditional texturing methods. Metal brooms will produce an adequate depth of texture. Recently, concrete pavements have been textured with the use of a fluted magnesium cylinder float. This method can produce a consistent texture equaled only be the best broom techniques and is finding favor. A specification currently exists for transverse tine texturing.

Curing

The high strength mortar aimed for in the mix design, well textured, will last only if proper curing is achieved to develop the high mortar strength. Therefore, an approved curing method should be used as early as possible to protect the concrete surface from excessive evaporation. The strength and durability of the textured surface that are vital for maintaining anti-skid properties can be adversely affected by shallow drying, which does not affect the overall quality of the concrete slab.

Materials

Since the textured surface is responsible for the friction characteristics of portland cement concrete, only in very severely worn surfaces is the coarse aggregate exposed. Therefore, it is the fine aggregate in the mortar that is important in these surfaces. Hence, the fine aggregate must be a hard, non-polishing type. Usually, a good angular silica sand provides an adequate fine aggregate. If locally-available sands are composed of polishing minerals, an imported or manufactured non-polishing fine aggregate must be used for high-volume roads.

Attempts have been made to improve the surfaces by sprinkling small quantities of hard, durable, fine aggregate particles onto the concrete immediately before final finishing. Current data from these experiments are inadequate for evaluation of their worth.

Experiments have been made with polymers to greatly strengthen concrete surface mortar. These experiments have been performed in concrete plants with accelerated curing facilities. No techniques applicable to concrete pavements have been developed.

In summary, the production of good anti-skid Portland cement concrete pavements requires the selection of the fine aggregate composed of non-polishing minerals plus the best available construction methods and techniques to produce a surface with good initial texture and the strength and durability to maintain that texture.

Bituminous Pavements

In new bituminous pavements we are probably concerned only with hot-mix pavements. These may be of two types, conventional, dense-graded asphaltic concrete and open-graded hot-mix.

Years of experience with dense-graded asphaltic concrete have produced specifications for grading limits that will provide an adequate initial macrotexture for good anti-skid properties. We might then concentrate on how those properties can be lost.

In the usual case the fine matrix will be worn away exposing the coarse aggregate. It is important then that the exposed coarse aggregate be non-polishing, as discussed earlier. There is, however, the possibility of losing the macrotexture. If mixes are poorly designed or overasphalted, the coarse aggregate may remain submerged in the matrix and channels for high-speed water escape are not available.

To accommodate the thermal expansion of the bituminous binder, it is important, particularly in an area such as Texas with high summer temperatures, that mixes be designed with the percentage of air voids as high as possible without impairing stability and durability. This ensures that the macrotexture will not be lost.

Thin, open-graded hot-mix pavements are a newer development than dense-graded asphaltic concrete. There is, however, sufficient experience that recommendations for aggregate gradation have been developed and the mixes can be used with some confidence (7).

What criteria, then, does one use to choose between using a conventional asphaltic concrete or a thin, open-graded hot-mix surface? Basically, the problem is reduced to one of economics. Where the locally available aggregates provide an adequate long-term microtexture, a conventional asphaltic concrete will provide the most economical long-term solution. On the other hand, if local aggregates are of the polishing type, a thin course of open-graded hot-mix using especially selected aggregates may be used to provide the required long-term anti-skid properties. In this latter case, local aggregates may be used in the asphaltic concrete base below the thin surface course.

It may be cost effective to delay the application of the special friction surface while the less desirable surface becomes polished. There are, however, two drawbacks to this procedure. First, the capital funds for the delayed treatment may be lost to other pressing projects. Second, the delayed work would cause traffic delays, so that any economic benefits in the delayed capital expenditure are lost in more costly construction plus traffic delays. This inconvenience to the driving public in the early life of a new road facility is poor public relations and should be avoided. It is thereby recommended that special anti-skid surfaces be placed as part of the initial construction.

Note: The use of a sprinkle treatment may be a satisfactory alternate to specifying ACP aggregate with a high polish value. For a full discussion of sprinkle treatment, see Report 214-4 entitled "Sprinkle Treatment - How, Why and Where."

Summary

As traffic volumes and speeds have increased, it has become apparent that wet-road accidents have also increased. While traffic accident data have identified sections of road with extreme wet-road accident rates, recently developed friction measuring techniques have demonstrated that the high wet-road accident rates are associated with low wet-road friction.

Since the identification of the wet friction problem, extensive re-research has been done. Methods of treating existing surfaces to improve wet friction, overlaying to improve friction, as well as building new surfaces that will have and maintain satisfactory wet friction have been developed. A basic understanding of the properties of road surfacing materials, as they relate to wet-road friction, has also been developed. Thus, it is now possible in designing a new road surface to select the materials and pavement design necessary to maintain adequate wet friction for the life of the surface. Remedial treatments for existing surfaces can also be tailored to the terrain, geometrics, environment and the volume and type of traffic. The purpose of this report is to delineate the alternatives available to the engineer to correct slippery pavements and to discuss the alternatives available to construct a pavement with an initial and prolonged high skid number.

Tables 1 and 2 summarize briefly the available treatments that provide wet-road skid resistance. Estimated costs have been reduced to an annual basis with an interest rate of eight percent. The reader is cautioned that factors other than least annual cost, such as delay cost to the driving public, hazards of maintenance operations and permissible added dead weight, must also be considered. The cost of added factors are not developed in this report.

Table 1 - PORTLAND CEMENT CONCRETE

TREATMENT	BRIEF DESCRIPTION	RECOMMENDATION	ESTIMATED COST $/yd^2$	EXPECTED LIFE YRS	ANNUAL/yd^2 COST @ 8%
NEW PAVEMENTS					
High Quality Mortar	Use Low W/C mixes with sharp siliceous fine aggregate textured by fluted cylinder or wire broom	All new Portland cement concrete surfaces	Incremental 0-0.50 (Depends on local availability of agg.)	20	0-0.05
TREAT EXISTING SURFACES					
Sandblast	Sandblast existing surface to remove polish	Not recommended Benefits minor & temporary	0.40	<1	0.40
Acid Etching	Remove polish by removal of aggregate by acid reaction	Not recommended Benefits minor & temporary	0.15	<1	0.15
Scabbling	Minor roughening of surface by impact tool	Not recommended Benefit minor	0.10	<1	0.10
Longitudinal Grooving	1/8" X 1/8" grooves 3/4" centers made by diamond or abrasive saws	Recommended for directional control	1.00	5	0.25
Transverse Grooving	1/8" X 1/8" transverse grooves at regular or random spacing	Recommended where cross drainage is poor and in braking areas	1.50	5	0.37
Diamond Grooving	3/8" X 3/8" grooves in two directions at 45° to centerline	Recommended for trial in sags and superelevation run-off areas	2.00	5	0.50

Table 1 - Continued

TREATMENT	BRIEF DESCRIPTION	RECOMMENDATION	ESTIMATED COST $/yd²	EXPECTED LIFE YRS	ANNUAL/yd² COST @ 8%
OVERLAY EXISTING SURFACES					
Portland Cement Concrete Overlay	Thin bonded patches or Thick structural course	Usually bridge decks only - Not recommended solely as anti-skid treatment	60.00	20	6.11
Chip Seal	Conventional Bituminous binder with anti-skid aggregate cover. Requires land closings	Recommended only where Road life is limited. Low first cost. Marginal for very high vols.	0.35	5	0.09
Rubberized Asphalt Chip Seal	As above with rubberized asphalt	As above	0.50	7	0.10
Hot Mix Asphaltic Concrete	Asphaltic concrete with selected non-polishing coarse aggregate	Recommended long life treatment. Use where ride improvement needed	1.50 minimum thickness	15	0.17
Asphaltic Concrete with Precoated Chips	Sprinkle treatment--precoated anti-skid chips rolled into surface	Recommended for high speed high volume facilities	1.50	15	0.17
Open-Graded Plant Mix Friction Course	High void open graded mix with non-polishing aggregate	Recommended thin surface over smooth, pavements structurally sound	1.50	10	0.23
Epoxy Seal	Sprayed epoxy binder with special non-polish fine chip cover	Recommended for bridge decks	10.00	10	1.50
Epoxy-modified	Epoxy-modified binder for greater strength and durability	Recommended for trial on high volume freeway with nonpolishing aggregate	7.50	25	0.85

Table 2 - BITUMINOUS SURFACES

TREATMENT	BRIEF DESCRIPTION	RECOMMENDATION	ESTIMATED COST $/yd^2	EXPECTED LIFE-YRS	ANNUAL/yd^2 COST @ 8%
TREAT EXISTING SURFACES					
Longitudinal or transverse grooving	1/8" X 1/8" grooves at 3/4"-1" centers sawn longitudinally or transversely	Recommended only in paved shoulders to aid lateral drainage	2.00	15	0.24
Heater-Planer	Remove excess asphalt from isolated fat spots by heating and scraping	Recommended for small areas. Preparatory treatment for overlay	0.40	5	0.10
Heater-with Chip Cover	Extended fat areas are heated and pre-coated chips spread and rolled in	Recommended for trial on low traffic volume roads	1.00	5	0.25
OVERLAY EXISTING SURFACES					
See Table 1 - Overlays for bituminous surfaces are similar.					
NEW PAVEMENTS					
Use non-polishing aggregate as for overlays.					

REFERENCES

(1) Skid Resistance, National Cooperative Highway Research Program, Synthesis of Highway Practice No. 14, Highway Research Board, 1972.

(2) Farnsworth, Eugene E. "Continuing Studies of Pavement Grooving in California" Special Report 116, Highway Research Board, 1971.

(3) Kummer, H.W. and Meyer, W.E. "Rubber and Tire Friction" Engineering Research Bulletin B-80, Pennsylvania State University, University Park, Pennsylvania, 1960.

(4) Gallaway, B.M. and Epps, J.A. "Current Methods for Improved Tire-Pavement Interaction" Proceedings of the American Society of Civil Engineers, Transportation Engineering Journal, Vol. 98, Note 4, November, 1972.

(5) Gallaway, B.M. "A Review of Current Methods for Producing Skid Resistant Pavements in the United States of America" Annual Proceedings, Association of Asphalt Paving Technologists, 1973.

(6) Gallaway, B.M. and Hargett, E.R. "Blending Lightweight Aggregates with Natural Aggregates for the Production of Bituminous Concrete" Research Record No. 273, Highway Research Board, Washington, D.C., 1969.

(7) Smith, R.W., Rice J.M., and Spelman, S.R. "Design of Open-Graded Asphalt Friction Courses," Federal Highway Administration Report No. FHWA-RD-74-2, Jan. 1974 (Interim Report).