Construction of Nonskid Pavement Surfaces

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•IN the broadest sense of the phrase, to a construction engineer, construction of nonskid pavement surfaces involves one of just two things—either building pavements initially with satisfactory skid-resistant surfaces or applying surface treatments to existing pavements to improve their skid resistance.

But, building pavements initially with satisfactory skid-resistant surfaces may be considered in terms of at least five major classifications of engineering and construction activity.

1. Application of geometric design criteria that provide for adequate profile grade, sight distance, radius of curvature, cross-slope and surface drainage.
2. Imposition of materials requirements and production controls that assure the use of hard durable aggregates with satisfactory qualities of angularity, particle size and polishing characteristics in pavement surface courses.
3. Properly designed and thoroughly blended surface-course paving mixtures that will permit full exploitation of the inherent skid-resistant qualities of individual components, e.g., asphalt-concrete mixes that will not flush and bleed in hot weather under traffic, or portland cement concrete that can develop adequate mortar strength to resist abrasion under heavy truck use, etc.
4. Execution of competent placing and finishing techniques so that the completed pavement surface possesses optimum texture characteristics in addition to proper geometric design features.
5. Timely and sufficient curing or protection of new pavement so as to assure retention of initial surface characteristics after the pavement is placed in service.

And, applying surface treatments to existing pavements to improve their skid resistance includes several additional construction activities such as grooving portland cement concrete pavement with diamond cutting equipment, applying seal coats, and resurfacing.

However, since the author is primarily concerned here with problems arising out of actual field construction practice, this presentation will be oriented to that outlook. Therefore, the sense in which the phrase "construction of nonskid pavement surfaces" is used for this article is somewhat narrower than that just outlined. This discussion will deal mainly with construction techniques utilized in placing and finishing new portland cement concrete pavement surfaces with slight excursions into techniques involved in securing nonskid asphalt-concrete pavement surfaces and in grooving existing portland cement concrete pavements to improve skid resistance.

NATURE OF THE PROBLEM

Everyone knows that a construction engineer must be constantly prepared to decide tough questions for which answers are not easy. In this matter of constructing skid-resistant pavements, though, there are many tough questions which even the most inventive, self-reliant engineer cannot now effectively answer. Perhaps the toughest question of all comes from the constructor who says, "I am ready to do anything necessary in the way of improving, changing or otherwise modifying my construction techniques—just what is it you want me to do to build a more nonskid pavement?"

What does the engineer reply to such a question? Does he specify a burlap finish, a broom finish, or some other as yet unknown type of finish? Should texturing be performed transversely, longitudinally, diagonally or in a diamond pattern, and how deep should the texture be made? Should portland cement concrete pavement finishing techniques be modified to assure a deeper grout layer at the surface, or to add specially selected particles of aggregate to the top surface course? Should the builder be required to meet a coefficient of friction specification for the completed pavement surface: a coefficient of friction requirement alone or in conjunction with some depth of texture specification? Should he also be required to satisfy some sort of a durability specification to help assure that the pavement surface will retain initial skid resistance?

These are difficult questions to answer and there are many others in a similar vein. However, reasonable answers to such questions are essential if engineers are to describe adequately and in terms of economical construction just what it is the builder must produce. The need is urgent.

REVIEW OF CONSTRUCTION PROCEDURES

Perhaps a review of construction procedures employed in California will be illustrative of some of the problems, if not the solutions. California practice has been chosen only because of the author's familiarity with it and not because it is necessarily more or less effective than that of other states.

ASPHALT-CONCRETE PAVING

Field construction procedures used in spreading and compacting asphalt-concrete pavements in California appear to have a very minor effect on the resulting skid resistance. Skid-resistance values on these pavements are generally very good but they can be either very good or very poor, depending upon whether the pavement bleeds or whether there was some other readily identifiable defect in the mix. However, because construction procedures in California appear to have such a minor effect on the resulting skid resistance of asphalt pavements, less attention will be given in this discussion to bituminous paving practices than to concrete paving practices.

It does deserve saying, though, that the favorable nonskid qualities achieved in these asphalt-concrete pavements are considered to derive principally from the physical characteristics of the aggregates and the method of mix design used.

Aggregates available in California for asphalt-concrete mixes are relatively polish resistant—limestones do not constitute a problem.

With respect to specification requirements for the aggregates, maximum particle size and combined grading is specified together with the permitted loss in the Los Angeles rattler test and the minimum percentage of crushed or naturally angular particles. Normally, the maximum particle size required is either ½ or ¾ in. (Table 1). The Hveem method of asphalt-concrete mix design results in mix with a lower asphalt content than does, for example, the Marshall method.

TABLE 1

AGGREGATE GRADING REQUIREMENTS FOR BASE COURSE AND SURFACE COURSES (Percentage Passing)

Sieve Sizes	Base Course	Surface Courses							
		¾-In. Max.			½-In. Max.			⅜-In. Max.	No. 4 Max.
		Coarse	Medium	Fine	Coarse	Medium	Fine		
1¼ In.	100								
1 In.	95-100	100	100	100					
¾ In.	80-95	90-100	95-100	95-100	100	100	100		
½ In.					95-100	95-100	95-100	100	
⅜ In.	50-65	60-75	65-80	70-85	75-90	80-95	80-95	95-100	100
No. 4	35-50	40-55	45-60	50-65	50-67	55-72	58-75	65-85	95-100
No. 8		27-40	30-45	37-52	35-50	38-55	43-60	50-70	70-80
No. 30	12-25	12-22	15-25	18-30	15-30	18-33	20-35	28-40	35-50
No. 200	2-7	3-6	3-7	4-10	4-7	4-8	6-12	7-14	7-16

One word of caution should be noted before this brief review of asphalt-concrete paving practices is concluded. Experience indicates that surface treatments sometimes lead to loss of skid-resistance value. For example, it is not uncommon to apply what in California is called a fog seal coat, a light (0.05 to 0.10 gal/sq yd) application of asphalt emulsion, to new asphalt-concrete pavements under the initial construction contract. This practice is quite generally beneficial; however, there are conditions which can produce undesirable results. Application of such a seal late in the year, or application of an excessive amount of asphalt for the particular pavement can result in low skid-resistance values.

PORTLAND CEMENT CONCRETE PAVING

Turning to construction practices in paving with portland cement concrete, it is apparent that the situation, with respect to the importance of placing procedures on skid resistance, is significantly different than for bituminous paving practice.

For portland cement concrete, as for asphalt concrete, the aggregates must be hard and durable, but for the former they must also be of such character that it will be possible to produce workable concrete within reasonable limits of water content.

In California, aggregate requirements are established with a view primarily of structural considerations, i.e., soundness, hardness, mortar strength and shrinkage. Qualities affecting the micro- or macro-texture that can be produced on a pavement surface are not considered in establishing such requirements.

For this article, surface texture means the geometrical form of the road surface, that is, the shapes of the surface protrusions (asperities) large and small, that make contact with the tire tread, or deform it, and the channels in between them. Micro-texture refers to fine-scale asperities; macro-texture refers to the larger-scale asperities and channels in between.

With respect to specification requirements for portland cement concrete, maximum particle size and grading of the combined aggregate is specified together with cement content and limiting values of slump and total water content (Table 2).

Contractors are given the option of using either 1½ of 2½-in. maximum combined aggregate grading and they with very few exceptions choose the 1½-in. maximum option.

Slump of paving concrete is generally held within a range of 0 to 2 in. and must not exceed 3 in. In terms of Kelly ball penetration, this is a range of 0 to 4 in. and a maximum of 6 in. The free water content is also not allowed to exceed 312 lb/cu yd.

Paving concrete is now produced almost exclusively in central-mixing plants moved in and set up specifically for the purpose on each paving project. The mix is transported to the paving site in ordinary end dump trucks and currently is placed through one of three makes of slip-form pavers: Blaw-Knox, Guntert-Zimmerman, or Concrete Machinery Incorporated.

The make of slip-form paver used has some influence upon the completed pavement surface condition. Certain accessory equipment items, such as the rotating screed, which may be either part of the original equipment or contractor's additions, also have an influence on the condition of the finished pavement surface.

It is reasonable to assume that adding additional water during the

TABLE 2

GRADING LIMITS OF COMBINED AGGREGATES

Sieve Sizes	Percentage Passing		
	2½-In. Max.	1½-In. Max.	1-In. Max.
3 In.	100		
2½ In.	95-100		
2 In.	80-95	100	
1½ In.	65-87	90-100	100
1 In.	50-75	50-86	90-100
¾ In.	45-66	45-75	55-100
⅜ In.	38-55	38-55	45-75
No. 4	30-45	30-45	35-60
No. 8	23-35	23-35	27-45
No. 16	17-27	17-27	20-35
No. 30	10-17	10-17	12-25
No. 50	4-9	4-9	5-15
No. 100	1-3	1-3	1-5
No. 200	0-2	0-2	0-2

finishing operation, or mixing bleed water with the surface mortar, will have significant effect on the strength and wear resistance of the surface and thus upon durability of the macro-texture. Since rotating screeds are conventionally considered to require the addition of water to function properly, use of this equipment may result in significant loss of wear resistance, assuming of course that an acceptable finish can be obtained by other techniques that do not result in equivalent loss. This is a controversial issue and slip-form pavers both with and without rotating screeds are used.

One make of slip-form paver currently used utilizes two heavy oscillating screeds as the primary means of shaping the pavement surface. Appearance of the completed surface confirms the logical conclusion that a deeper layer of grout is produced than with pavers utilizing a conforming (extrusion) screed. Any effect this may have upon the effectiveness or durability of the completed surface texture is also controversial and use of the equipment is not restricted on this basis.

Following the slip-form paver, hand-finishers repair defects in the surface, such as tear marks and edge slump. The entire surface is then screeded with a pipe float or a diagonal wood float. Generally, three passes of these devices are sufficient to eliminate minor variations in the surface due to differential compaction, tear marks, etc.

It is quite common to see a fine spray of water being added to the surface to facilitate the action of pipe and diagonal wood floats, or the timing of the operation is such as to cover the span of the concrete bleeding period so that excess water from this source is intermixed with the surface grout. Here again, the necessity for and effect of these techniques with respect to the effectiveness and durability of the completed surface texture is controversial.

As with the addition of water at rotating screeds on certain pavers, or in connection with handwork, paving inspectors attempt constantly to restrict the use of additional water to only that lost from the surface by evaporation. Unfortunately, this is an activity in which finishers and others in the paving crew all too frequently resist and circumvent whenever possible.

The final finishing operations are to texture the surface and then apply curing compound. There is little doubt that initial skid-resistance values depend largely on effectiveness of the texturing operation. There is even less doubt that durability of the initial nonskid texture is to a very important degree dependent on effectiveness of the cure. These final finishing operations are, therefore, much more critical than the attention ordinarily given them would indicate.

Texture is routinely accomplished by use of burlap drags or the combination of an initial burlap drag and a final longitudinal brooming with nylon bristle brooms.

Curing is accomplished by spraying the fresh concrete surface with white pigmented curing compound at the rate of 150 sq ft/gal. Compliance with the specified application rate is checked by comparing quantities of compound expended with the area of pavement surface covered, either on a spot check or continuing basis. Caution must be exercised, however, because the application rate rarely if ever equals the expended rate. This, of course, is due to several factors but without doubt the major factor is wind drift. Thus, many occasions occur when the spray rate must be increased, or the area given a double application of compound in order to assure effective curing.

Timeliness in applying the compound is probably as important, if not more so, than the rate of application in achieving an effective cure and thus long-lasting nonskid surfaces. Delay in applying curing compound is a widespread and commonly overlooked shortcoming in most warm weather paving operations. It occurs because curing must follow the hand-finishing and texturing operations. Timing of the texturing operation is routinely a compromise, since concrete pavements rarely lose surface moisture uniformly. Optimum texturing, at least when burlap drags and brooms are used, occurs when the wetter spots have dried enough to reasonably hold the texture, but before the drier spots have dried too much to texture at all. However, in terms of optimum curing, this usually means that the drier areas are too dry.

A partial solution to this dilemma is to speed up and improve the effectiveness of final finishing operations. Improved equipment such as the combined pipe float-burlap drag-curing compound applicator recently making an appearance on California paving projects would appear to be an important advance in the right direction. It is suggested that an even more important advance would be the incorporation or improvement of metering screeds at the receiving end of slip-form pavers to reduce the slight variations in surface condition that are one of the primary causes of localized excessively wet spots.

Some progress in this direction is evident in the widespread use of box spreaders ahead of some pavers, or in the auger at the front end of one paver, or contractor modifications such as strike-off paddles added to other pavers.

The completed pavement may be opened to traffic as early as 10 days following concrete placement, unless Type III cement is used and an earlier opening is permitted in writing by the engineer. In that event the pavement may be opened to traffic as soon as the concrete has developed a modulus of rupture of 450 psi.

California specifications require that new pavements must have a coefficient of friction of not less than 0.30 as determined by Test Method No. Calif. 342 (see p. 119 of this publication).

The construction aspects that can be expected to affect performance of new concrete pavement surface texture would seem to be as follows:

1. Nature of the concrete aggregate.
2. Amount of mixing water used.
3. Nature and amount of any admixtures used.
4. Cement factor.
5. Nature and amount of surface manipulation in finishing.
6. Amount of additional water used during finishing.
7. Amount of bleed water mixed into surface mortar.
8. Timing of finishing operations.
9. Method and depth of texturing.
10. Orientation of texture serrations.
11. Timing of the curing operation.
12. Effectiveness of curing materials, as applied.
13. Extent of curing period before pavement is opened to traffic.
14. Amount of abuse by construction equipment in constructing appurtenant facilities.
15. Extent of bump cutting to meet smoothness requirements.

GROOVING EXISTING CONCRETE PAVEMENT

Grooving hardened portland cement concrete pavement to improve skid resistance is becoming an increasingly important construction technique. This work is done currently through the use of two different makes of concrete planing machines: the Concut Bumpcutter and the Christensen Concrete Planer. In each case, a cutting arbor of multiple diamond saw blades separated by appropriate spacers produces a series of parallel grooves in the pavement surface.

When grooving an existing pavement, California engineers have generally adopted a grooving pattern in which $\frac{1}{8}$-in. grooves spaced at $\frac{3}{4}$ in. on centers are cut at $\frac{1}{8}$-in. minimum depth. However, a recent innovation has been to utilize 0.095-in. wide blades instead of the $\frac{1}{8}$-in., that is 0.125-in., blades to cut narrower grooves. The narrower groove pattern may produce less disturbance in the control of motorcycles operated over the grooved pavement and other advantages.

The features of grooving that can be expected to affect skid resistance are as follows:

1. Width and depth of grooves.
2. Spacing of grooves.
3. Amount of lane width grooved.
4. Orientation of groove pattern, i.e., longitudinal, transverse, or other.

California pavements are grooved longitudinally on the premise that lateral resistance to skidding on curved alignment by highway vehicles is improved over that of transverse or diagonal grooving. Substantially the whole lane width is grooved, omitting only about 12 in. adjacent to each lane line or edge of pavement.

One of the newest construction developments with respect to grooving is the introduction by equipment manufacturers of vacuum devices which permit the removal of water and cutting residue concurrently with the grooving operation. This should greatly reduce the hazard to traffic created when water is allowed to flow across active lanes of pavement.

CONCLUSION

Before concluding this brief examination into the relationship of construction procedures and skid-resistant pavement surfaces, it may be well to seek the view point of the highway user. Can it be doubted that in his eyes the only thing actually being done about improving his protection from skids is what is presently being constructed into the roadways he drives on or the vehicles and tires he uses?

Engineers and scientists realize that, as in the case of building Rome, construction of the optimum in nonskid pavement surfaces cannot be accomplished in a day. However, improvement can be realized a step at a time.

Much is now being accomplished by way of enlarging the technical understanding of tire-pavement interactions and means of measurement. Hopefully many of the papers presented at this summer meeting of the Highway Research Board will contribute to the growing knowledge. Important as this may be, though, sight must not be lost of those areas of activity in which improvements can be made in the skid resistance of existing pavements and those currently being built.