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16. ABSTRACT
A study was conducted to investigate methods of obtaining more durable skid resistant Portland cement concrete pavement surfaces. The primary factors studied were curing and texturing methods, and quality of the surface mortar.
The report is divided into three parts.
I. Curing Compounds and Surface Hardeners
The surface hardeners tested did not show any significant effect on surface texture durability. Two of the curing compounds tested proved to be superior in performance to the older products and are now specified in State work.
II. Surface Texturing Methods
Numerous texturing methods were studied in the Laboratory. The more promising ones were then tested in the field. These were (1) a device for imparting longitudinal grooves in the plastic concrete surface; (2) a stiff bristled broom used either longitudinally or transversely; and (3) the broadcasting of various types of aggregates onto the fresh concrete surface. In addition, the pavement on one project was grooved with diamond saw blades before being opened to public traffic.
Brooming longitudinally has shown the most promise to date and has been adopted by most California paving contractors as their standard texturing method. Transverse brooming as tried on one project, resulted in excessive texture loss at an early age.

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16. Abstract (continued)

Brooming longitudinally has shown the most promise to date and has been adopted by most California paving contractors as their standard texturing method. Transverse brooming as tried on one project, resulted in excessive texture loss at an early age.

III. Surface Mortar Quality

On a number of projects tests were made on mortar obtained from at least three locations: (1) wet screened from concrete in front of the paver; (2) scraped from the pavement surface directly behind the paver; and (3) scraped from the surface following finishing. Results show that, on the average, about 45% of the potential compressive strength of the mortar is lost during the placing and finishing operation. Between 15% and 30% loss occurs due to the placing and shaping operation and appears unavoidable. The remainder is due to the finishing procedure, bleeding action of the concrete, and water added to aid in finishing. Effects on strength are also corroborated by surface abrasion tests and water-cement ratio determinations.

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION AND RESEARCH
TRANSPORTATION LABORATORY

January 1975

FHWA No. B-3-1
TL No. 633126

Mr. R. J. Datel
Chief Engineer

Dear Sir:

I have approved and now submit for your information, this interim research project report titled:

PCC PAVEMENT TEXTURE QUALITY INVESTIGATION

Study made by . . . . . Concrete Branch

Under the Supervision of . . . . . D. L. Spellman, P.E.

Principal Investigator . . . . . J. H. Woodstrom, P.E.

Co-Investigators and
Report Prepared by . . . . . B. F. Neal
R. J. Spring, P.E.

Very truly yours,

JOHN L. BEATON, P.E.
Chief Engineer,
Office of Transportation Laboratory

Attachment

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This project was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration, under Agreement No. B-3-1. Follow-up on the work reported herein and additional experimental work is being carried on under Agreement No. D-3-49, "Improve PCC Wearing Surfaces".

The contents of this report reflect the views of the Office of Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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INTRODUCTION

With an increasing emphasis on traffic safety, the problem of skid resistance has gained in importance (4). Skid resistance has become a popular subject and of course is related to the surface texture (or lack of it) of the pavement. Skid surveys and accident data pointed up the need for improvement in this facet of pavement construction. Grooving of slippery pavements has been found to greatly reduce accidents and since about 1967 grooving of California pavements has steadily increased, reaching a peak in 1972.

Year	Square Yards	Cost
1967	94,800	$ 72,000
1968	149,000	122,000
1969	609,000	432,000
1970	1,343,000	731,000
1971	4,341,000	1,489,000
1972	6,088,000	3,130,000
1973	3,964,000	1,845,000

Nearly all of this grooving has been done in valley or coastal areas where there is no chain traffic. Pavement surface wear or polishing is a national problem although in most northern states loss of texture has been attributed to the use of studded tires (1,3,4) and chains, together with abrasion from sand used for ice and snow control. An NCHRP project (2) is directed toward this problem, however, most of the polishing of our pavements has occurred outside the snow areas and is attributed to wear caused by large volumes of rubber-tired traffic.

In California, few studded tires are used in snow areas; texture loss is mainly caused by chain action. Fortunately the "bush-hammered" surface created during winter months retains sufficient skid resistance through the summer, and loss of concrete through wear has been of greater concern than skid resistance. At the

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present time, there appears to be no practical method of eliminating chain wear. Therefore, this study is mainly directed toward finding ways of prolonging the effective life of concrete pavement surfaces in the valley and coastal areas. Previous studies (5) have shown that abrasion resistance is proportional to compressive strength. Since texture of concrete pavement is created from surface mortar, a test method was developed that could measure the relative strength and abrasion resistance of a surface. An abrasion test for concrete was adapted from one used for measuring abrasion resistance of asphaltic concrete. Using this test, the effects of curing, finishing, admixtures, and surface coatings was studied in the laboratory (5). What was finally needed, however, were field tests which could show the effects of field conditions that could be related to maintaining surface texture (and acceptable skid resistance) for a longer period of time. Potentially the savings were great. If changes could be made that would prolong the life of the texture even 4 or 5 years, the costs of grooving to restore surfaces to a safe condition could be greatly reduced. Over a period of 7 years, nearly $8 million was expended for grooving. The age of the pavements grooved in 1973 varied from about 6 to 18 years with no large grouping at any particular age. For a group of 31 grooving projects completed in 1973 for which pavement ages could be verified, the distribution was as follows: (Some grooving jobs covered portions of two contracts paved at different dates.)

Age when Grooved, Years	Number in Age Group
6	5
7	0
8	2
9	2
10	3
11	3
12	2
13	3
14	2
15	5
16	3
17	2
18	3
	35

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This shows that although some surfaces have a relatively short nonskid life, it is possible to construct surface textures having substantially longer life. In fact, three other pavements grooved in prior years were 20, 22, and 37 years old when first grooved. Of course traffic has a greater influence on texture life but all concrete mainline pavements have very high traffic indices, a general requirement for selection of pavement. One of the purposes of this study was to determine factors that affect texture life (other than traffic) and develop ways of improving texture durability thereby eliminating a potential hazard to the motorists.

It is generally accepted that specifications now in use for concrete pavement were developed to insure structural adequacy and reasonable smoothness. A minimum skid resistance value is intended to control the final texturing operation. There are no requirements for surface mortar strength or durability, nor are there specific restrictions in the specifications governing the amount of water that can be added to the surface during the finishing operations, though through specific concrete design procedures and limits on consistency, structural strength has been adequate.

Concrete finishing conditions are known to have a great influence on the overall quality of the surface mortar. Field conditions are often grossly different from those in a laboratory. For example, bleeding of the same concrete observed in the field can be quite different depending on weather conditions. If there is a hot, dry wind, one may not observe any bleedwater even though bleeding is occurring at a fairly rapid rate. Indeed water may have to be applied to forestall plastic cracking. On the other hand, under conditions of no wind and high humidity, excessive bleed water may collect causing a finishing problem.

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Proper finishing of slabs is an art. The various steps involved must be properly timed and executed for optimum results. While the general principles for obtaining high quality surfaces are well known (6), field conditions vary and therefore operations must be varied to meet changing conditions. Some of the more common factors affecting pavement texture durability are:

1. Time and amount of floating.
2. Amount of water incorporated into the mortar during floating.
3. Time at which texture is formed.
4. Configuration of the texture.
5. Curing.

With these general thoughts in mind, the project was divided into three parts, though some parts were conducted concurrently.

Part 1. Investigate ways of improving service life of the initial texture by use of better curing compounds and/or surface hardeners.

Part 2. Investigate ways of prolonging the effective texture life by use of special texturing devices, and

Part 3. Investigate ways of prolonging initial texture life by improving the quality and durability of the surface mortar.

CONCLUSIONS

Part I CURING COMPOUNDS AND SURFACE HARDENERS

Two curing compounds, one a resin base type and the other a chlorinated rubber type, were found to be superior in overall

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qualities to the wax/resin base compounds. The improved performance was due in part to more uniformity of the product as well as improved moisture retention properties and a viscosity which resulted in a more uniform coverage of the textured surface.

The two surface hardeners tested in the field, linseed oil and a chlorinated rubber epoxy, did not provide significant benefits in pavement surface wear. (In laboratory tests, application of either of these products to hardened concrete surfaces resulted in a significant increase in abrasion resistance.)

After up to six years of service, skid measurements show no clear-cut differences between the various compounds tested.

Part II SURFACE TEXTURING METHODS

Of the experimental texturing methods tried in the field, a stiff bristled broom brushed longitudinally on the pavement was considered the most satisfactory. Broadcasting of aggregate on the plastic concrete surface appears to be a promising method but needs further evaluation.

Transverse brooming as tried on one project resulted in excessive texture loss at an early age as determined by skid tests and visual observations.

Part III SURFACE MORTAR QUALITY

From tests on mortar taken from concrete in front of the paver and from the pavement surface, results indicate that an average of 45% of the potential mortar strength is lost due to placing and finishing operations. A significant portion of the loss is due to normal placing and shaping operations, and appears unavoidable. The remaining loss is due to floating, bleeding of the concrete, and water added ostensibly to aid in finishing.

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IMPLEMENTATION

The chlorinated rubber and petroleum hydrocarbon resin base curing compounds have been adopted for use and are now required by the Standard Specifications.

Due, at least in part, to the experimentation reported here, many paving contractors now use brooms for texturing concrete pavements.

PART I

CURING COMPOUNDS AND SURFACE HARDENERS

A. Curing Compounds

The importance of proper curing of PCC pavement surfaces cannot be over-emphasized. Even with the best of concrete mixes, ideal weather, and using specified placing and finishing procedures, a good cure is necessary to obtain strong and durable surfaces. When improperly cured, surfaces usually have a "dead" appearance and the texture wears off rapidly under traffic.

In California, either liquid curing compounds or waterproof membranes are permitted for curing concrete pavement, but pigmented curing compounds are used almost exclusively. At the beginning of this study, the type of curing compounds most often used was a wax/resin type. Although acceptable under certain conditions, several undesirable features were associated with these products.

1. Maintaining the solvent, pigments, and wax/resins in a completely mixed condition was difficult, especially in cold weather.

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2. Nonuniformity in production resulted in varying water retention properties.

3. With the advent of deeper texturing, the compound was noted to run excessively into the low areas. This made uniform coverage of asperities of the texture extremely difficult.

4. The film formed by the compound was weak and "tracked" or "picked up" easily when disturbed during the first few days after placing.

It was thus desirable to find or develop an improved formulation in order to meet some of the new demands of curing the more deeply textured surfaces. A number of materials were considered with five being selected for testing. These have bases of (1) chlorinated rubber; (2) petroleum hydrocarbon resin; (3) acrylic resin; (4) tall oil; and (5) linseed oil. Laboratory tests indicated that with the exception of linseed oil, all materials selected had satisfactory water retention properties. Therefore, it was decided to field test two commercial formulations of chlorinated rubber (Trikote 26 and CR-4), and laboratory formulations of petroleum hydrocarbon resin, acrylic resin, and tall oil. These field tests will be discussed later.

B. Surface Hardeners

A number of products have been promoted for surface treatments to provide harder surfaces and improved scale and abrasion resistance. Those selected for laboratory study were (1) linseed oil anti-spalling compound; (2) chlorinated rubber epoxy (Trikote 18, similar to Trikote 26, but with less solids); (3) polyester with mineral spirits; (4) epoxicised urethane; (5) two proprietary products with unknown formulations.

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Abrasion tests were made on laboratory fabricated specimens treated with these compounds. When compared with similar but untreated specimens, the linseed oil and Trikote 18 products produced the most improvement in abrasion resistance and were selected for field testing.

Field Tests

1. I-680 near Pleasanton

Test sections were constructed on this project using Trikote 26 curing compound and both linseed oil and Trikote 18 as surface hardeners.

From laboratory tests of the chlorinated rubber products, an application rate of 300 sq ft/gallon was determined to be adequate for good water retention. The actual rate of application for the 24-ft wide by 725-ft long test section was about 250 sq ft/gallon. Coverage appeared to be very satisfactory and sufficiently uniform. The only adverse reaction by observers was to the extreme whiteness and "wet look" of the pavement surface. The section was most noticeable when compared to the somewhat gray appearing surface cured with the wax/resin base compound. The equipment used to spray the chlorinated rubber products had to be cleaned with a special solvent. The solvent in the curing compound and that used for flushing attacked some of the rubber parts of the spraying equipment which necessitated extensive cleaning work and replacement of some parts with materials resistant to the solvent.

The surface hardeners were applied to the pavement after the concrete was 14 to 21 days of age. They were sprayed directly on surfaces which had been cured by wax/resin type curing

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compound (not removed prior to application of the hardeners). The Trikote 18 was applied in a one-coat operation to a total pavement length of 1100 ft. The calculated rate of application was 250 sq ft/gallon. Linseed oil was applied to a pavement length of 800 feet in a two-coat operation. The first coat was applied at a rate of 240 sq ft/gallon and the second, at 540 sq ft/gallon. While this was slightly more than the rates of 400 and 600 sq ft/gallon recommended by the supplier, no problems were encountered in absorption into the pavement or drying of the oil.

2. I-5, near Arbuckle

Three curing compounds were selected for testing on this project: (1) acrylic base; (2) Trikote 26; and (3) resin base. No surface hardeners were included.

Serious problems were encountered in attempting to spray the acrylic compound on the pavement surface. The material would not cover the full area between spray bars, apparently because it was too viscous. A 400-ft length (24 ft wide), was finally covered by making two separate passes with slightly different alignment of the machine. No further attempt was made to use the material on this project. The application rate was about 80 sq ft/gallon, much heavier than the planned rate of 250 sq ft/gallon. The material applied at this heavy rate also resulted in a very white surface, although nonuniform due to the problems encountered with the spray operation.

Approximately 4000 lineal feet of pavement was cured with the Trikote 26. Although some nonuniform areas were noted, the calculated average spread rate was 200 sq ft/gallon.

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Another 4000 lineal feet of pavement was cured with the resin base product. The actual spread rate was approximately 200 sq ft/gallon, slightly higher than the 250 sq ft/gallon planned, but appeared to be a very uniform coverage. No problems were encountered in application.

3. I-5, near Kettleman City

Three curing compounds were tested on this project: (1) Trikote 26; (2) resin base; and (3) tall oil. No surface hardeners were included.

Approximately 4000 lineal feet of pavement, 24-ft wide, were cured with Trikote 26, 8800 feet with resin base, and 4500 feet with tall oil. Application rates were 225 sq ft/gallon for the first two , and 250 sq ft/gallon for the tall oil. Coverage was considered satisfactory for all sections.

Another trial with the acrylic compound using a revised formulation had been planned on this project. Unfortunately, the truck carrying the material to the job was involved in an accident and the compound was lost.

4. State Route 152, near Los Banos

The curing compounds tested on this project were tall oil and CR-4, a chlorinated rubber product. No surface hardeners were included.

Each compound was used to cure approximately one mile of pavement. Application rate for the tall oil was 200 sq ft/gallon and for the CR-4, 250 sq ft/gallon. No problems were encountered in applying either compound.

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5. I-5, near the Oregon Border

The only experimental product used on this project was the linseed oil antispalling compound as a surface hardener. Two portions of the roadway were treated, a 1-mile section of the northbound lanes that had been opened to traffic about a month, and a 1-mile section of the southbound lanes that had been under traffic for about a year.

In the northbound lanes, two coats of compound were applied on two consecutive days in hot weather and there were no problems with absorption or drying. In the southbound direction, both coats were applied on the same day in cool cloudy weather. The first coat was applied at 1000 hours and the second at 1500 hours, even though the initial coat was still tacky. The extremely slow drying resulted in traffic having to remain diverted on the shoulder until 1830 hours. Even then, speed controls had to be enforced through the area for about half an hour longer. After that amount of traffic, the pavement was no longer considered hazardous and was reopened without restrictions.

D. Evaluation

The evaluation of the various sections was based on one or more of the following:

1. Skid resistance measurements.
2. Abrasion resistance of cores.
3. Compressive strength of cores.
4. Photographs and visual observations.

Performance of the curing test areas was compared to adjacent control sections which had not received any special treatment, but were cured with the standard wax/resin base curing compound.

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Skid measurements were made in the outer wheel track using California's portable tester, according to Test Method No. Calif. 342. Initial measurements were obtained before the roadway was opened to public traffic and then periodically afterwards. Results of these measurements to date are shown in Table 1.

While there is some variability in results, there does not appear to be any significant difference in friction coefficient changes between test areas and adjacent control areas. Overall, skid measurements appear to be influenced by unidentified factors, and, in some cases, skid resistance appears to have increased with age.

On some projects, cores for abrasion and compressive strength tests were obtained so that testing could be done when the concrete was 28 days of age. This was varied in Section 2 where tests were made at 42 days with additional tests at 20 months. Results are shown in Table 2.

The 42-day abrasion and compressive strength results of cores from the control section for the acrylic compound indicate considerably weakened concrete. The reason for this was not discovered. The improved abrasion resistance shown for the linseed oil treated sections was about the amount expected based on laboratory tests. (See Appendix 1 for test method used to determine abrasion loss.) However, a survey of Section 5 after one winter of traffic following treatment showed that scaling and/or chain wear had removed much of the concrete surface in both treated and untreated areas. Occasional monitoring has continued but no significant difference in performance can be detected. It is doubtful that linseed oil applied to the pavements in chain areas is of any lasting value, but it may be effective in reducing scaling of nonair-entrained concrete not subject to chain traffic.

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Table 1

Skid Resistance Measurements - Part I
(Test Method No. Calif. 342)

Field Test Number	Treatment	Skid Numbers (Avg. of 2-12 Readings) 1967	1968	1969	1970	1971	1972	1973	1974
	Curing Compounds								
1	TriKote 26	34	30	32	30			23	
	Control	35	32	33	31			24	
2	TriKote 26	31	31	32	34			33	
	Control	31	34	34	35			36	
3	TriKote 26		30			33	28		28
	Control		36			37	33		29
4	CR-4			37	31	28	26	31	26
	Control			41	31	31	25	33	26
2	Acrylic Base	28	31	32	33			31	
	Control	33	32	34	35			31	
3	Tall Oil		31			34	35		38
	Control		36			24	24		21
4	Tall Oil			37	30	29	23	30	24
	Control			38	29	27	25	32	27
2	Resin Base	31	31	32	34			31	
	Control	33	29	30	32			28	
3	Resin Base		30			34	33		35
	Control		36			34	34		35
	Surface Hardeners								
1	TriKote 18	31	31	32	31			25	
	Control	33	32	32	30			26	
1	Linseed Oil	32	30	32	31			26	
	Control	34	31	32	31			26	
5	Linseed Oil	Not made							
	Control	"	"						

(1) Controls were all cured with wax/resin compounds.

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Table 2

Test Results of Cores from Field Installations

Field Test Number	Type of Treatment	Abrasion Loss, Grams Age 28 days	42 days	20 mos.	Compressive Strength, PSI Age 28 days	42 days	20 mos.
	Curing Compounds						
1	TriKote 26	22			5200		
	Control	21			5030		
2	TriKote 26		23	13		4520	6310
	Control		26	15		4450	5950
3	TriKote 26	17			3920		
	Control	17			3880		
4	CR-4	12			3970		
	Control	11			4190		
2	Acrylic Base		17	14		5110	6110
	Control		36	15		3950	5950
3	Tall Oil	18			4190		
	Control	16			4320		
4	Tall Oil	11			3890		
	Control	11			4510		
2	Resin Base		25	15		4840	6210
	Control		20	15		4990	5950
3	Resin Base	18			4540		
	Control	16			4320		
	Surface Hardeners						
1	TriKote 18	21					
	Control	21					
1	Linseed Oil	18					
	Control	22					
5	Linseed Oil	18					
1	Control	21					

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E. Additional Testing

An additional laboratory test program was conducted to compare the chlorinated rubber curing compound to the wet mat curing method specified for bridge deck concrete. A series of small 6-inch thick slabs were constructed outdoors at the laboratory with forms kept about 1.5 feet above the ground to simulate a bridge deck. The curing variables were:

Slab A. When sheen disappeared from surface, a thoroughly soaked mat was placed on the slab and kept wet for the 7-day curing period, after which time the mats were removed and the slab permitted to cure in the ambient atmosphere.

Slab B. No curing of any type.

Slab C. As sheen disappeared from the surface, white chlorinated rubber curing compound was applied at a rate of 250 sq ft/gallon. The following morning, a thoroughly soaked mat was placed on the slab and kept wet for the remainder of the 7-day curing period.

Slab D. As sheen disappeared from the surface, white chlorinated rubber curing compound was applied at a rate of 250 sq ft/gallon. No additional moistening or curing.

Note: All slabs were subjected to the same outdoor ambient conditions of humidity and temperature.

To reduce the effects of variables occurring in materials, placing, finishing, curing, weather, testing, etc., three slabs for each curing condition were made over a period of time. Maximum ambient temperature during the cure period ranged from

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92° to 99°F, which represented typical summer curing conditions for California Valley areas. Three 4-inch cores from each slab were taken for each of three test ages. Average compressive strength results are shown in the following tabulation.

		PSI		
		4-days	28-days	63-days
Slab A	Wet Mat	5200	5650	6500
Slab B	No Cure	2920	3220	3590
Slab C	Chlorinated Rubber & Mats	4530	5100	5830
Slab D	Chlorinated Rubber only	3980	4470	4630

The adverse effect of no cure is readily apparent. The concrete cured with chlorinated rubber and wet mats had strengths equal to about 90% of that cured with wet mats continuously. While this strength loss is undesirable, it must be pointed out that maintaining wet mats in the field under hot windy conditions is often difficult. There is also a tendency on the part of some contractors to delay placing mats until a fairly large area is ready for cure. This practice can lead to drying shrinkage cracking as well as reduced concrete strength. The use of chlorinated rubber curing compound followed by wet mats applied no later than the following day may result in as good or better cure than that actually being achieved in the field with the wet mat method alone.

F. Discussion

From tests and observations of performance, all the special curing compounds tested except the acrylic type, were considered satisfactory for protecting the concrete from undue moisture loss. The acrylic was not adequately tested due to the difficulties described. The chlorinated rubber and resin type compounds have been adopted for use by the State and formulation and application

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requirements appear in the Standard Specifications. Contractors have the option of using either type on PCC pavements. Since the resin base type is lower in cost, it is used almost exclusively on pavements, where a choice is available. The use of a chlorinated rubber compound is now required on all concrete bridge decks as a preliminary cure and is followed by wet mat curing starting no later than the morning following concrete placement.

The surface hardeners tested were not considered sufficiently beneficial to adopt for routine use.

PART II
SURFACE TEXTURING METHODS

A. Texturing Devices

For many years the most common method used for texturing PCC pavements in California was the burlap (or carpet) drag. When drags are properly constructed, kept clean, and used at the ideal time, a good texture can usually be formed. However, the "ideal time" can be short and there can be varying thicknesses of surface mortar with differential drying, all of which contribute to unsatisfactory results. The burlap drag finish is usually sandpaper-like in appearance and in almost all cases, will meet the formerly specified minimum coefficient of friction of 0.25. In 1967, the requirement for friction coefficient on new pavements was increased to 0.30. The difficulty sometimes experienced in meeting this new requirement pointed up the need for improvements in texturing methods. In some cases, where barely adequate initial texture was obtained during construction, normal wear (not chain wear) resulted in an early loss of skid resistance.

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In attempting to develop better texturing methods, numerous ideas for texturing devices were considered. From these, ten experimental devices were constructed for laboratory testing. Each device was used to texture a portion of a concrete slab and was evaluated by visual observations and skid resistance measurements. Following are observations made on each:

1. Steel Wire Broom

The friction coefficient was high and the texture appeared safe for all types of traffic. The device was judged as "very promising". (See Figure 1.)

2. Stiff Bristled Broom

Results were very similar to the wire broom, though perhaps not quite as harsh textured. Very promising. (See Figure 2.)

3. Steel Rod Comb

Larger aggregate near the surface prevented the comb from making a smooth pass through the plastic concrete. Some of the aggregate particles were dragged along or plucked out by the device resulting in a very rough surface texture. Considered unsatisfactory. (See Figure 3.)

4. Flexible Surface Groover

This device, made from spring steel and Ram-set nails, gave results very similar to the steel rod comb. It, too, was considered unsatisfactory. (See Figure 4.)

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5. Blocked Out Mesh Roller

The roller gave what was considered to be a good texture at times, but tended to ride up and over some aggregate particles near the surface causing very uneven results. Additional weight applied to the roller while texturing did not appear to improve results. Considered unsatisfactory. (See Figure 5.)

6. Large Steel Washer Groover

Although very heavy and difficult to handle, this device produced a satisfactory texture. In appearance, the texture was similar to that produced by diamond grooving existing pavement to prevent skidding accidents. With some modification this idea might prove feasible. (See Figure 6.)

7. Steel Runner Sled Groover

This device produced a grooved texture similar in appearance to that produced by the steel washers. It was much easier to handle, however, and was considered more adaptable to field use than the washer device. (See Figure 7.)

8. Steel Sprocket Roller

This roller produced a texture with a lower coefficient of friction than anticipated. It was also felt that since there were no continuous channels for the escape of water, the skidding hazard would be increased. (See Figure 8.)

9. Transmission Belting

In its original form, the belting had a flexible rubber rib about 0.1-inch wide by 0.2-inch high spaced on 0.25-inch centers. It

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was felt that this spacing was probably too close, so part of the section was modified. On one part, the ribs were left intact; on another, every other rib was removed leaving one rib every 0.5-inch; and on third portion, two of every three ribs were removed to provide 0.75-inch spacing. With weights added, the device produced reasonably good texture, especially with the 0.5-inch and 0.75-inch spacings, but coarse aggregate near the surface and nonuniform setting of the surface mortar caused uneveness in the texture depth. The texture was also similar to that obtained with the steel runner device. (See Figure 9.)

10. Steel Decking Roller

This device was made with decking with raised rosettes irregularly spaced. It was formed into a cylinder so that the rosette components would be diagonal to traffic when rolled transversely across the slab. Results indicated that the surface between the rosettes was too smooth and that the indentations would likely trap water as with device No. 8. (See Figure 10.)

As a result of the laboratory study, the steel runner sled (no. 7), and the stiff bristled broom (no. 2), were selected for field trial. The selections were based on several factors:

a. A satisfactory friction coefficient.

b. Subjective opinion on whether or not the surface would be excessively rough or would create objectionable levels of tire noise. Rougher textures would also result in faster tire wear.

c. Opinions as to effect of texture on all types of vehicles. (Experience with various grooving patterns

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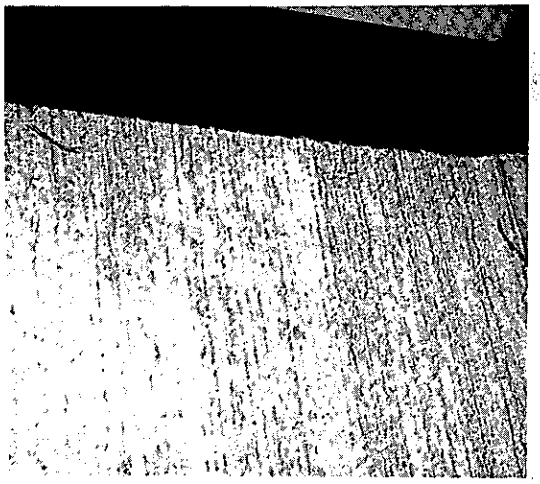

Figure 1. Steel Broom Texture

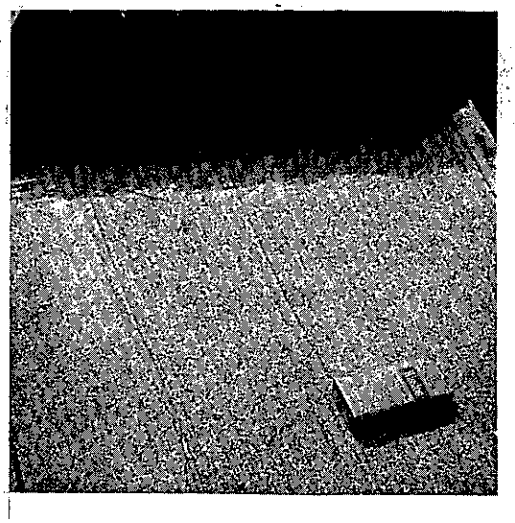

Figure 2. Stiff Bristled Broom Texture

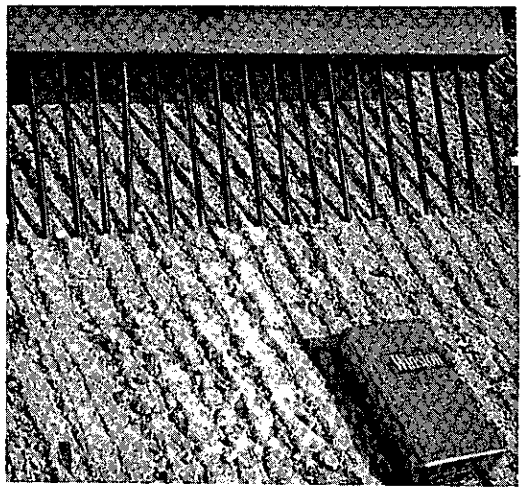

Figure 3. Steel Rod Comb Texture

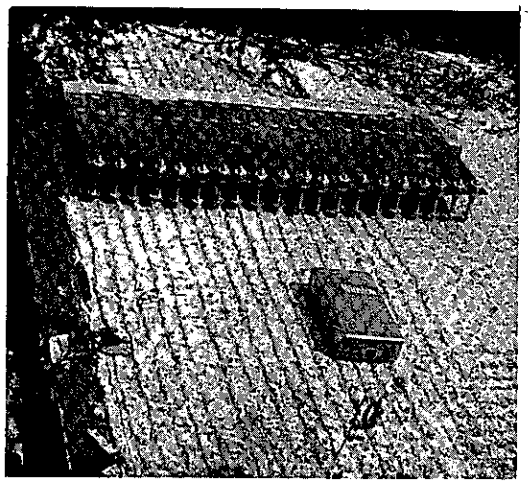

Figure 4. Flexible Groover Texture

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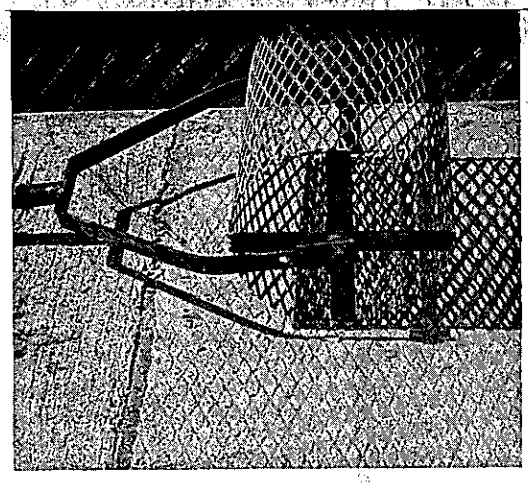

Figure 5. Blocked Out Mesh Roller Texture

Figure 6. Steel Washer Texture

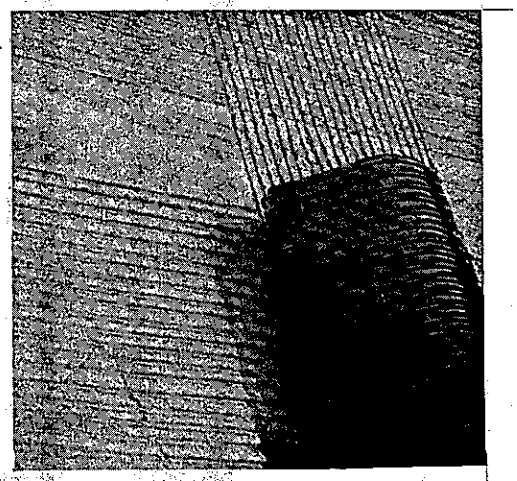

Figure 7. Steel Runner Sled Texture

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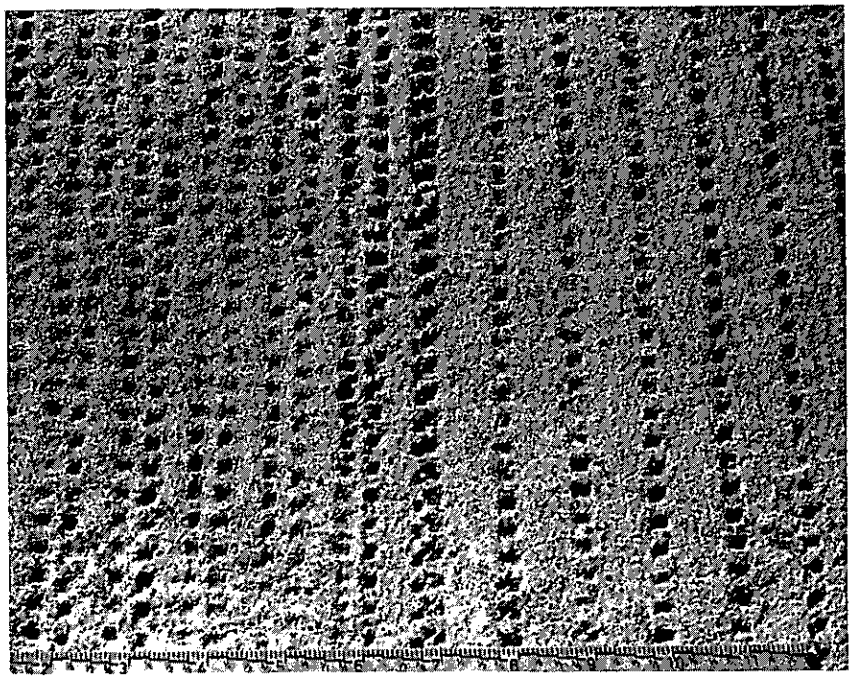

Figure 8. Steel Sprocket Roller Texture

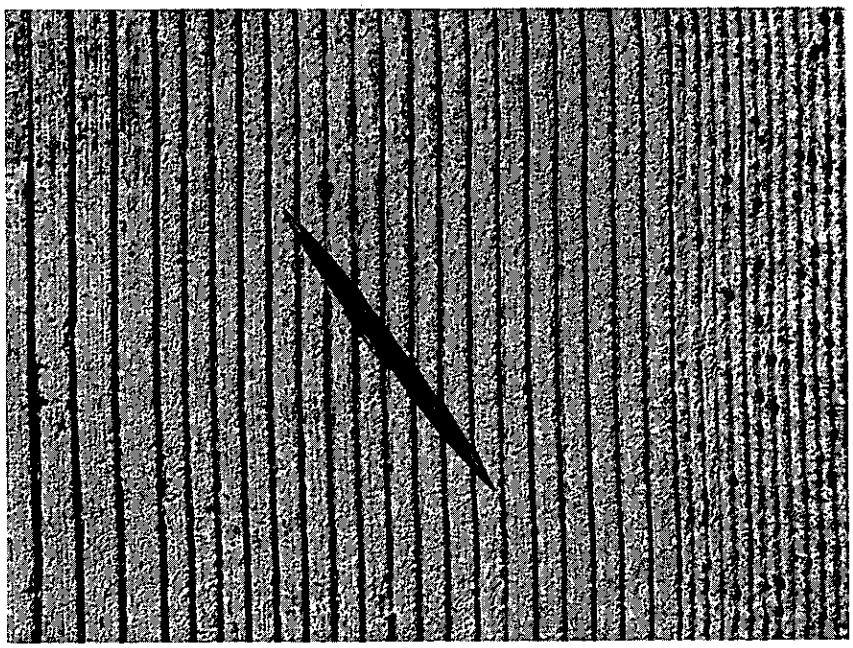

Figure 9. Transmission Belting Texture, Different Rib Spacings

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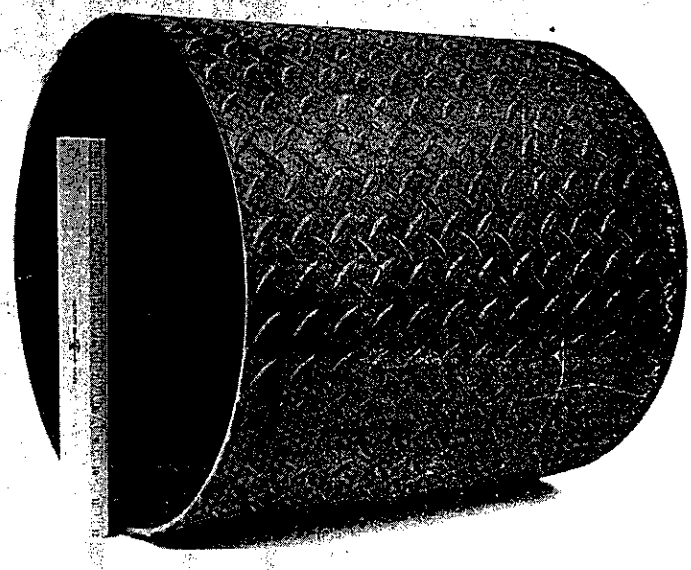

Figure 10. Steel Decking Roller

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has shown that some configurations of grooved texture can create steering problems for certain compact cars and most motorcycles.)

d. The grooves produced by the steel runner sled appears to be more adaptable to field construction than the other devices that produced longitudinal grooves.

It was also considered that the broadcasting of selected aggregates on the plastic concrete surface might provide a better skid resistant surface. The aggregates chosen for field tests were:

a. A crushed relatively fine but hard sand used for sandblasting.

b. Steel slag aggregates in either 3/8-inch by No. 8 size, or No. 4 by No. 16. The slag was a hard, crushed product and, since it is vesicular by nature, it was felt that good skid resistance qualities would remain even as the particles were worn down by traffic.

c. A crushed quartz aggregate in 3/8-inch by No. 8 size.

An additional method of texturing suggested was grooving of the pavement surface while it was still plastic. Since a machine to accomplish this was not available, it was decided to try a section of pavement grooved with diamond saws while the concrete was relatively green and perhaps easier to cut.

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B. Texturing Test Sections

1. I-680, near Pleasanton

The methods selected for this project were the steel runner sled, the stiff bristled broom, and sandblasting-sand broadcast on the surface of the fresh concrete. All three test sections were very short. The sled was used for 50 feet, the broom for 25 feet, and the sandblasting sand for 100 feet.

The texture left by the sled pulled longitudinally was semi-circular depressions approximately 1/4-inch in diameter with a slight ridge on each side of the depressions. The result appeared to give a good skid resistant surface.

The broom was also used longitudinally with a resulting texture that was considered entirely satisfactory.

The sandblasting sand was broadcast on the surface by hand and after dragging with burlap, there was no noticeable difference in texture. The spread rate was not determined but was judged to be fairly light.

2. I-5, near Arbuckle

The methods selected for this project were the sled and broom devices, slag aggregate in both the 3/8-inch and No. 4 sizes, and sandblasting sand. Again, the test sections were short, the sled being used for 150 feet, the broom for 50 feet, the 3/8-inch slag for 100 feet, the No. 4 slag for 150 feet, and the sandblasting sand for 170 feet.

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The aggregates were all spread by hand at the approximate rate of 0.2 lb per sq ft. This low rate was selected because it was considered that difficulties would be encountered in obtaining adherence to the surface mortar if too many particles were spread. The aggregates were applied following the finishing float and prior to the burlap drag texturing. All three sections appear to have satisfactory texture.

3. SR 152, near Los Banos

The experimental texturing methods on this project were the broom, 3/8-inch slag, and 3/8-inch crushed quartz. The test lengths were 300 feet, 100 feet, and 100 feet for the three respective sections.

For this project, the broom was used to texture transversely. This texture looked good and appeared to be sufficiently skid resistant.

The spread rate for the aggregates was about 0.3 lbs per sq. ft, or about 50% greater than on the previous project. On one-half of each section, only a burlap drag was used after application of aggregate, but on the other half, a pipe float was employed to help depress the aggregate into the mortar, then followed by the burlap drag. The effect of the pipe float can readily be seen in Figures 11 and 12.

4. SR 58, near Boron

The only experimental texturing on this project was the grooving with diamond saw blades. The grooving contractors had stated that by grooving the concrete at an early age and without having to worry about public traffic, the cost would probably be less

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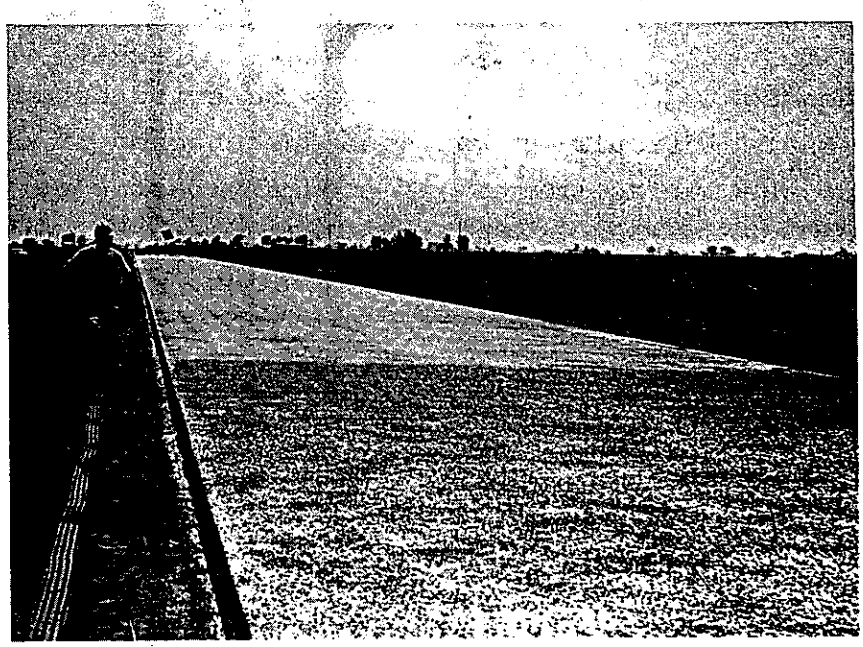

Figure 11. Aggregate Broadcast on Surface.
(Burlap Drag Only)

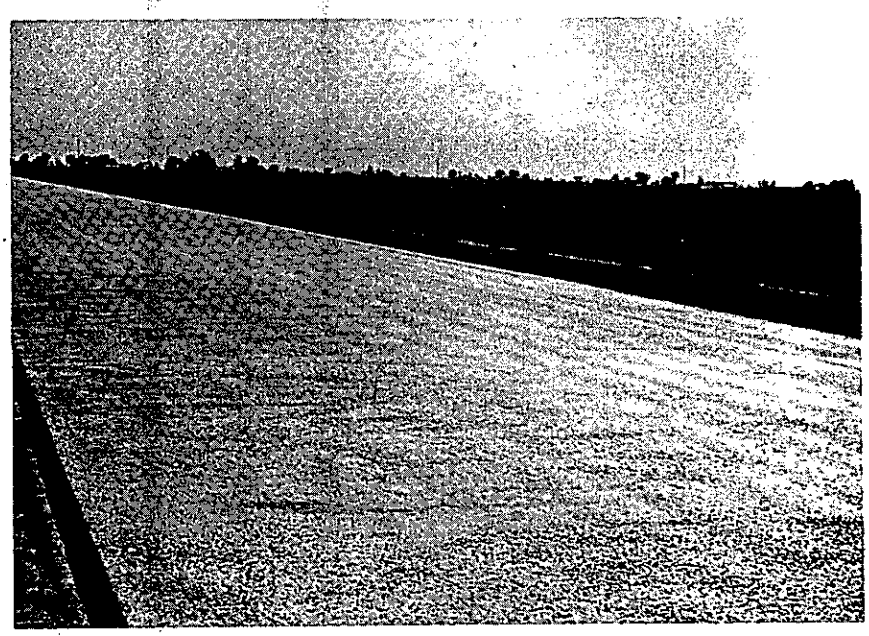

Figure 12. Aggregate Broadcast on Surface.
(Pipe Floated, then Burlap Drag)

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than half that of grooving old pavements. As often happens the work did not go as planned. Specifications called for the vacuum pickup of cuttings, but the Contractor's vacuum equipment extended beyond the pavement edge and could not be used (without modification) until shoulders were constructed. Consequently, grooving was not even started until about five months after the pavement was constructed. A little over two miles was eventually grooved, however. The initial texture was applied by a burlap drag.

C. Discussion

Skid measurements in the outer wheel track were made in all the test sections and in adjacent control sections in accordance with Test Method No. Calif. 342. Results are shown in Table 3. An attempt was also made to measure texture depth with a modified sand patch test. This test, which uses a fixed frame that is filled with sand, was thought to be an improved version of the original. However, results proved to be highly variable between operators and were so erratic they were not used in evaluation of texture. Three dimensional type photographs are also being taken periodically, but until better methods of interpretation are developed, they will not be of much aid in evaluating texture wear.

As a result of the apparent success of the sled device on short trials, it was decided to build a larger device and try it on a longer section. About 2000 feet of pavement were grooved with this sled. Before opening to traffic, the Highway Patrol was asked to check the ride with motorcycles. It was their conclusion that the pavement was very hazardous to motorcyclists and probably to compact cars as well. This was due to the configuration of the texture and the fact that the grooves did

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Table 3

Skid Resistance Measurements - Part II
(Test Method No. Calif. 342)

Section Number	Texture[1]	Friction Coefficients (Times 100) 1967	1968	1969	1970	1971	1972	1973
1	Steel runner sled	38	35	37	35			36
	Control	35	32	33	30			29
	Stiff bristled broom	41	35	37	34			34
	Control	37	35	34	31			29
	Sandblasting sand	34	31	33	30			27
	Control	35	32	33	30			27
2	Steel runner sled	32	34	35	32			32
	Control	31	33	33	31			31
	Stiff bristled broom	33	34	33	34			30
	Control	31	33	33	35			32
	3/8" slag aggregate	32	33	33	35			30
	Control	30	33	32	35			30
	No. 4 slag aggregate	32	32	32	33			33
	Control	32	32	34	33			31
	Sandblasting sand	32	33	35	37			31
	Control	30	33	32	36			31
3	Transverse							
	Stiff bristled broom			39	29	17	26	19
	Control			38	38	22	31	22
	3/8" slag aggregate			38	30	27	28	24
	Control			37	29	24	31	28
	3/8" crushed quartz aggr.			39	36	29	35	29
	Control			36	35	29	35	28
4	Diamond saw grooving					37		38
	Control					37		36

[1] All control sections were textured with burlap drag.

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not run perfectly straight. The entire test section was ground until the ride was considered safe for all traffic. No other testing was done on this project and the sled device was discarded.

The skid resistance of the transversely broomed section has declined at a high rate (see Table 3), and is not permitted by current specifications. Most California paving contractors now use longitudinal brooming as the routine texturing method.

The broadcasting of aggregate on fresh concrete surfaces is still considered a promising method of obtaining a durable skid resistant texture. Additional test sections on a larger scale were recently completed using a mechanized method of aggregate spreading. Since these sections are not yet open to public traffic, no performance data are available.

PART III
SURFACE MORTAR QUALITY

This research effort was directed toward determining the effects of concrete placing and finishing procedures on the quality of pavement surfaces. The addition of some water to the surface either directly behind the paver, in front of the finishing float, or both, is common practice by most paving contractors. This practice was known to be detrimental to surface quality but to what extent had never been determined. The type and amount of floating following placement was another factor which had never been evaluated. To develop the needed information, testing was performed on several projects during pavement construction.

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A. Testing Procedure (First Series)

On the first seven projects, the following procedure was used. Mortar samples were obtained from the paving concrete and fabricated into (1) 2-inch cubes for compressive strength tests, and (2) specimens for abrasion tests by the test method shown in the Appendix. Three specimens for each test were made from all samples. At each test location, mortar samples were taken during two or more stages of construction as follows:

Sample "A" was fabricated from mortar screened from the fresh concrete deposited in front of the paver, representing the potential quality of the mortar.

Sample "B" was fabricated from mortar scraped from the pavement surface (see Figure 13) immediately following the paver and at the same general location along the grade as the "A" sample. In a number of cases, water was added to the pavement surface by equipment attached to the back of the paver, resulting in some "B" samples being wetter (higher water-cement ratio) than others.

Sample "C" was fabricated from mortar scraped from the surface (adjacent to the "B" sample location) following one or more passes of the float.

Sample "D" was fabricated from mortar scraped from the surface immediately before the curing seal was applied. These samples were taken to determine the combined effects of further floating, evaporation of surface moisture after obtaining "C" samples, and added water (if any). A variation in obtaining "D" samples was made on a few projects but is described later.

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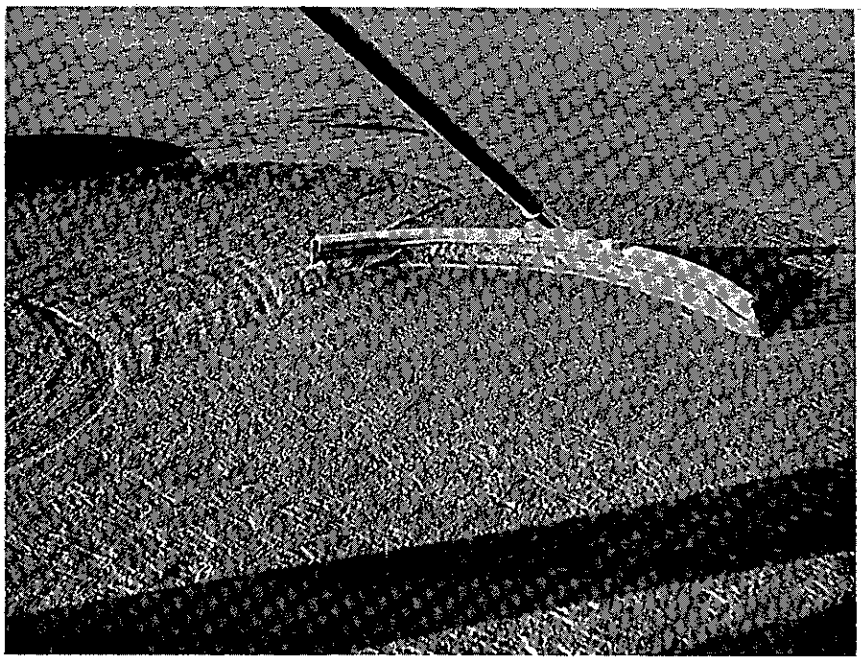

Figure 13. Obtaining samples of surface mortar.

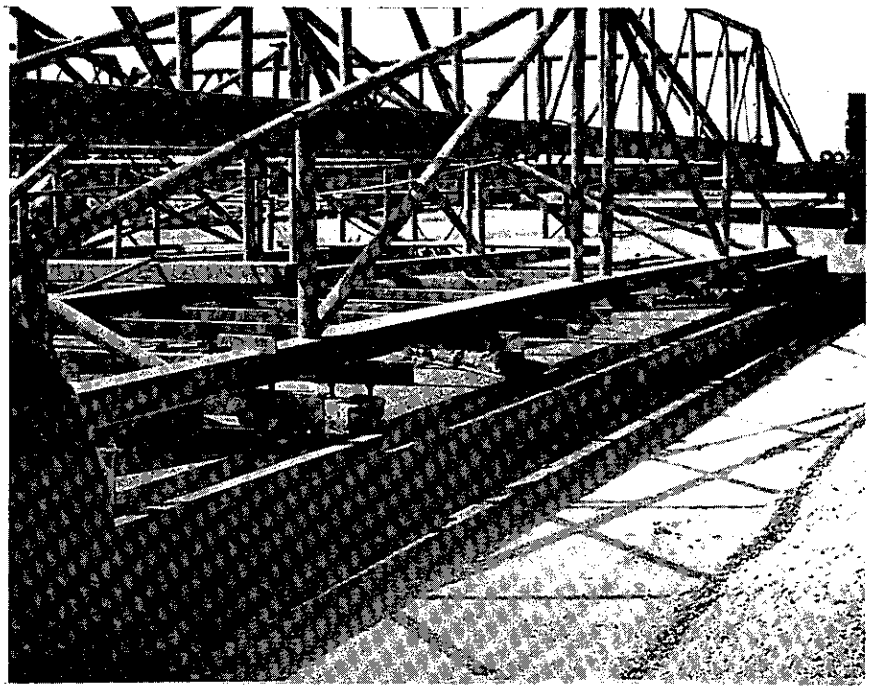

Figure 14. Wooden float used during finishing operations.

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The compressive strength and abrasion tests were all performed at 7 days of age.

It should be kept in mind when comparing results, that the "A" samples are fabricated from mortar obtained by wet screening concrete through a No. 4 sieve. In comparison to the wet screened mortar samples, the sample scraped from the surface may contain more fines as well as bleed water and/or added water. If no water were added to the paver before the "B" samples were obtained, this mortar could be considered as the best quality mortar available for forming texture.

B. Field Tests

1. SR 58, near Boron (Contractor A)

The slipform paver used on this project was equipped with a rotating screed on the rear. A water pipe fitted with 50 jets was used at times for spraying a film of water over the screed. The normal procedure during the paving of this project was to use only 12 of the jets. Also, behind the paver a burlap drag was attached to provide more uniform distribution of the surface water. During part of the testing, six of the twelve jets were turned off to check on the effects of varying amount of added water. An additional variable for a portion of the project was the omission of the pipe float as a finishing tool. Hand finishing was also held to the minimum. Normal finishing techniques include hand floating of uneven areas and at least two passes of a pipe float. Final texturing was by burlap drag.

A total of 11 sets of "A" and "C" samples were taken on this project. Results of compressive strength and abrasion tests are shown in Table 4. With the Contractor's normal operation

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Table 4

Boron Project

Sample Number	No. of Float Passes	Water Added by Paver	Water Added by Float	Compressive Strength at 7 days, PSI A	B	C	D	Abrasion Loss, Gms. A	B	C	D
1	0	Yes	No	5220		2530		14		21	
2	0	Yes	No	5460		3030		12		15	
3	0	Yes	No	5630		3700		10		14	
4	0	Yes	No	5530		4670		13		14	
Average				5460		3480		12		16	
5	0	Yes*	No	5110		4760		14		15	
6	0	Yes*	No	5480		4380		14		14	
7	0	Yes*	No	5440		3380		13		13	
Average				5340		4170		14		14	
8	2	Yes	No	5440		2950		13		20	
9	2	Yes	No	6190		2680		11		22	
10	2	Yes	No	5060		2600		12		19	
11	2	Yes	No	4980		3680		10		13	
Average				5420		2980		12		19	

A - Samples taken in front of the paving machine.
B - Samples taken from surface immediately following the paving machine.
C - Samples taken from surface after listed float passes.
D - Samples taken from surface just before texturing.

* 50% less water added by paver than remainder of samples.

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(Samples 8 - 11), there was an average of 45% loss in mortar stength from the time concrete was deposited on grade until final finishing. When floating was omitted (Samples 1 - 4), the loss was 36%; and when both floating and half the water was omitted (Samples 5 - 7), the loss was only 22%. The abrasion tests generally follow the same pattern showing higher losses with added water and additional surface manipulation.

2. I-5, near Carlsbad (Contractor B)

The slipform paver on this project was equipped with two flat oscillating screeds. Water was not added at the paver. Following the paver was a large self-propelled finishing float utilizing heavy wooden members for working the surface. (See Figure 14.) During normal operation, this float may make 6 or 8 passes, sometimes cutting and other times just smoothing. This results in a fairly thick layer of surface mortar in places. Water was added during some of the passes using a hose and spray nozzle. Texture was applied by a burlap drag attached to the rear of the float.

Some of the "C" samples were taken after one pass of the float, and others were obtained after three passes. Test results are shown in Table 5. The reduction in mortar strength was about 50% after one pass of the float and 57% after three passes. The abrasion losses of the "C" samples were substantially higher than the "A" samples.

3. I-5, near Oceanside (Contractor C)

The slipform paver had a rotating screed attached to the rear. Finishing was accomplished with a mechanically operated pipe float and texturing by a burlap drag followed by a stiff bristled broom. During normal paving operations, water was added both

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Table 5

Carlsbad Project

Sample Number	No. of Float Passes	Water Added by		Compressive Strength at 7 days, PSI				Abrasion Loss, Gms.			
		Paver	Float	A	B	C	D	A	B	C	D
1	1	No	Yes	6680		3850		12		16	
2	1	No	Yes	8330		3380		12		16	
3	1	No	Yes	7020		4080		10		14	
4	1	No	Yes	7220		3480		10		20	
Average				7310		3700		11		17	
5	3	No	Yes	6510		2790		13		17	
6	3	No	Yes	7180		3560		13		17	
7	3	No	Yes	8270		2660		10		21	
8	3	No	Yes	7110		3420		13		18	
Average				7270		3110		12		18	

A - Samples taken in front of the paving machine
B - Samples taken from surface immediately following the paving machine.
C - Samples taken from surface after listed float passes.
D - Samples taken from surface just before texturing.

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at the paver and the float. During testing this was varied for two sections by shutting off all water at the paver in one instance, and at the float in another. "A", "B", and "C" samples were taken on this project. "C" samples were made after 2, 3, or 4 passes with the float. Results are shown in Table 6.

Varying the number of float passes from 2 to 4 did not appear to have a significant effect on compressive strength and abrasion resistance. As expected, the "C" samples had the greatest loss when water was added at both the paver and float. The variation in results is probably due only to the amount of water that was added and worked into the surface. Water added at the paver only appeared to have slightly more detrimental effect than when added at the float only.

4. US 50, near Sacramento (Contractor C)

The Contractor and paving equipment on this project was the same as at Oceanside (project 3). During testing, water was added at the paver only. "C" samples were taken after either two or four passes of the float. A few "B" samples were also obtained. Two "D" samples were taken just before texturing and following four more float passes. Test results are shown in Table 7.

As before, the "B" and "C" samples indicated a considerable loss in strength and abrasion resistance. Strength losses after four float passes were slightly greater than those after two. Abrasion losses after four passes of the float were increased about 50%.

5. I-5, near Mendota (Contractor B)

The Contractor and equipment was the same as at Carlsbad (project 2). During testing, no water was added at the paver and while

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Table 6

Oceanside Project

Sample Number	No. of Float Passes	Water Added by Paver	Water Added by Float	Compressive Strength at 7 days, PSI A	B	C	D	Abrasion Loss, Gms. A	B	C	D
1	4	Yes	No	5000	4140	3060		14	14	21	
2	3	Yes	No	4930	3800	2980		15	17	20	
3	4	Yes	No	5360	3900	3020		13	17	23	
Average				5100	3950	3020		14	16	21	
4	4	No	Yes	5420	4730	3600		12	14	15	
5	4	No	Yes	5440	3350	3600		15	18	20	
6	4	No	Yes	5910	4000	3870		14	19	20	
Average				5590	4030	3690		14	17	18	
7	2	Yes	Yes	5700	2950	2260		15	25	37	
8	2	Yes	Yes	5870	3430	3680		15	24	19	
9	2	Yes	Yes	6270	3380	3460		12	19	22	
10	4	Yes	Yes	5530	3130	3130		15	21	26	
Average				5840	3220	3130		14	22	26	

A - Samples taken in front of the paving machine.
B - Samples taken from surface immediately following the paving machine.
C - Samples taken from surface after listed float passes.
D - Samples taken from surface just before texturing.

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Table 7

Sacramento Project

Sample Number	No. of Float Passes	Water Added by Paver	Water Added by Float	Compressive Strength at 7 days, psi A	B	C	D	Abrasion Loss, Gms. A	B	C	D
1	2	Yes	No	4370		2640		13		24	
2	2	Yes	No	5810		1980		12		23	
3	2	Yes	No	4630		2220		12		25	
4	2	Yes	No	4990		2520		13		21	
5	2	Yes	No	4830		2780		15		14	
Average				4930		2430		13		21	
6	4	Yes	No	4570		1640		14		50	
7	4	Yes	No	4970		1840		13		47	
8	4	Yes	No	4990		2070		12		33	
9	4	Yes	No	5110		2750		14		28	
Average				4910		2070		13		40	
10	4	Yes	No	5040	2200	2020		16	21	26	
11	4	Yes	No	4360	2160	2000		14	30	31	
12	4	Yes	No		2360	2330	2500		22	30	21
13	4	Yes	No		2520	2070	2260		18	23	24
Average				4700	2310	2110	2380	15	23	28	23

A - Samples taken in front of the paving machine.
B - Samples taken from surface immediately following the paving machine.
C - Samples taken from surface after listed float passes.
D - Samples taken from surface just before texturing.

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the normal procedure was to add water during floating, even this was shut off for a number of tests (I-5). "C" samples were taken after either one or two passes of the large wooden float. The "D" samples were taken after about four passes of the float and a pass of the burlap drag. Test results are shown in Table 8.

The results of the "C" tests followed the pattern of previous tests. Strength loss was slightly greater when water was added during the one float pass. The strength loss of the "B" samples was only about 17%, somewhat less than previous tests where some water was added at the paver. Though only 3 "D" tests were made. There was a slight decrease in strength and abrasion resistance which indicates excessive floating is detrimental.

6. US 101, near San Ardo (Contractor D)

The paver on this project had a rotating screed. Floating was by a hand-pulled pipe, and burlap was used for texturing. No water was added at the paver but was added during the floating operation. "A", "B", and "C" samples were taken, the latter after two passes of the pipe float. Results are shown in Table 9.

Strength results were similar to those obtained at Mendota - about 18% loss for the "B" samples and 35% for the "C" samples. Very little difference was shown in abrasion losses.

7. I-5, near Los Banos (Contractor E)

The slipform paver employed here had oscillating screeds rather than rotating. A mechanically operated pipe float was used for finishing and texture was applied by broom. Water was added at the paver but none during floating. Only "A", "B", and "C" samples were taken, the latter after four passes of the float. Test results are shown in Table 10.

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Table 8

Mendota Project

Sample Number	No. of Float Passes	Water Added by Paver	Water Added by Float	Compressive Strength at 7 days, PSI A	B	C	D	Abrasion Loss, Gms. A	B	C	D
1	1	No	Yes	3720	2980	2450		13	18	20	
2	1	No	Yes	4280	3610	2880		15	17	18	
3	1	No	Yes	4160	3920	2950		12	16	19	
4	1	No	Yes	4750	3840	3520		13	16	15	
5	1	No	Yes	4490	3510	2830		15	14	17	
Average				4280	3570	2930		14	16	18	
6	2	No	No	4970	4000	2500		12	17	24	
7	2	No	No	4020	3380	2670		15	17	21	
8	2	No	No	4330	3550	3350		14	15	16	
9	2	No	No	3830	3830	3460		15	18	15	
10	2	No	No	4400	3530	3580		15	15	17	
Average				4310	3660	3110		14	16	19	
11	2	No	No	4430	3600	2750	2870	14	17	18	19
12	2	No	No	4630	3890	3760	3480	12	16	14	16
13	2	No	No	4890	3860	3920	3270	13	15	14	16
Average				4650	3780	3480	3210	13	16	15	17

A - Samples taken in front of the paving machine.
B - Samples taken from surface immediately following the paving machine.
C - Samples taken from surface after listed float passes.
D - Samples taken from surface just before texturing.

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Table 9

San Ardo Project

Sample Number	No. of Float Passes	Water Added by		Compressive Strength at 7 days, PSI				Abrasion Loss, Gms.			
		Paver	Float	A	B	C	D	A	B	C	D
1	2	No	Yes	5450	4490	3190		15	16	18	
2	2	No	Yes	5630	4730	2580		17	14	21	
3	2	No	Yes	6180	4320	4260		13	14	14	
4	2	No	Yes	6420	4460	4030		11	13	13	
5	2	No	Yes	5300	4230	2910		15	14	15	
6	2	No	Yes	5180	4620	3550		14	15	16	
7	2	No	Yes	6050	4700	3450		15	15	17	
8	2	No	Yes	6360	4940	5200		14	13	13	
9	2	No	Yes	6220	5580	4470		12	11	12	
10	2	No	Yes	5660	4720	2980		13	14	13	
11	2	No	Yes	5940	5120	4080		11	11	15	
12	2	No	Yes	5670	5450	5020		15	12	15	
13	2	No	Yes	6470	5720	4190		13	11	12	
14	2	No	Yes	6600	5320	3960		15	11	15	
Average				5940	4890	3850		14	13	15	

A - Samples taken in front of the paving machine.
B - Samples taken from surface immediately following the paving machine.
C - Samples taken from surface after listed float passes.
D - Samples taken from surface just before texturing.

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Table 10

Los Banos Project

Sample Number	No. of Float Passes	Water Added by		Compressive Strength at 7 days, PSI				Abrasion Loss, Gms.			
		Paver	Float	A	B	C	D	A	B	C	D
1	4	Yes	No	5580	4230	3110		11	12	14	
2	4	Yes	No	4790	----	3310		10	14	13	
3	4	Yes	No	5030	3210	3780		10	14	13	
4	4	Yes	No	4550	2000	3230		10	19	13	
5	4	Yes	No	6040	2070	3350		10	18	11	
6	4	Yes	No	5290	3290	3290		13	14	15	
7	4	Yes	No	4880	3050	3080		12	16	13	
8	4	Yes	No	5280	2650	2450		10	18	19	
9	4	Yes	No	4530	2700	2400		12	15	16	
10	4	Yes	No	4810	2530	3140		10	16	15	
11	4	Yes	No	4730	2150	3860		13	21	15	
Average				5050	2790	3090		11	16	14	

A - Samples taken in front of the paving machine.
B - Samples taken from surface immediately following the paving machine.
C - Samples taken from surface after listed float passes.
D - Samples taken from surface just before texturing.

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The "B" samples show even a greater strength loss than the "C" specimens. This was probably due to the fact that the pipe float actually scraped some of the excessively wet mortar from the surface and discharged it over the pavement edge. Abrasion tests also show an apparent improvement in abrasion resistance between the "B" and "C" samples.

C. Testing Procedure (Second Series)

To aid in evaluating the surface mortar, a test method was developed to determine relative water-cement ratio. The method involves finding cement content by titrating 150-gram samples of mortar, and determining water content by drying a 1000-gram sample. While determination of water is not accurate due to some forced hydration of the cement which uses up free water during the drying, it was considered suitable for checking relative values of the samples obtained during the testing program. For this second series, the "D" samples were made with wet screened concrete obtained from the full thickness of the completed slab rather than with mortar scraped from the surface. Since this required additional work for the Contractor in backfilling and hand finishing, only a few such tests were made. Abrasion tests were not included in this test series.

A total of six projects representing five different paving contractors were visited during this second series.

1. I-5, near Weed (Contractor F)

This contractor used a paver with a rotating screed which was followed by a mechanically operated pipe float. Texturing was by both burlap drag and broom. Water was not added at the paver, but was added during floating. As a result of using

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harsh aggregates, the Contractor was having a difficult time in finishing. In some areas, additional mortar had to be mixed and placed on the surface. This interfered with the sampling procedures so that a valid comparison of mortar strength was not obtained. This was also a trial run for the W/C ratio test, and it was found that one man could not keep up with all the testing necessary for "A", "B", and "C" samples. While the testing was not completed as planned, much was learned about procedures.

2. I-805, near San Diego (Contractor B)

The operation on this project was the same as previously described for this contractor, (Carlsbad, Project 2, Series 1). Water was not added at the paver but was during almost every one of several passes of the wooden float. The compressive strength results are shown plotted in Figure 15 as average strength at each sampling point versus the average W/C ratio at that point. Each value is an average of four tests. The results clearly indicate that the compressive strength of the surface mortar is dependent upon the W/C ratio.

3. I-5, near Woodland (Contractor E)

This Contractor's operation was previously described (Project 7, Series 1); however, on this project, finishing was accomplished with a hand-pulled pipe float. Water was added at the paver by a hose on the high side of the slab. This water was allowed to run across the pavement to aid in floating. Average strength versus W/C ratio is shown plotted in Figure 16. The effect of water added at the paver is obvious from comparing "B" Samples to the "A" samples. Further strength loss from the floating operation is relatively small but the increase in W/C ratio was also correspondingly small. The strength of the "A" and "D" samples were about as expected.

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Figure 15 TEST RESULTS - SAN DIEGO

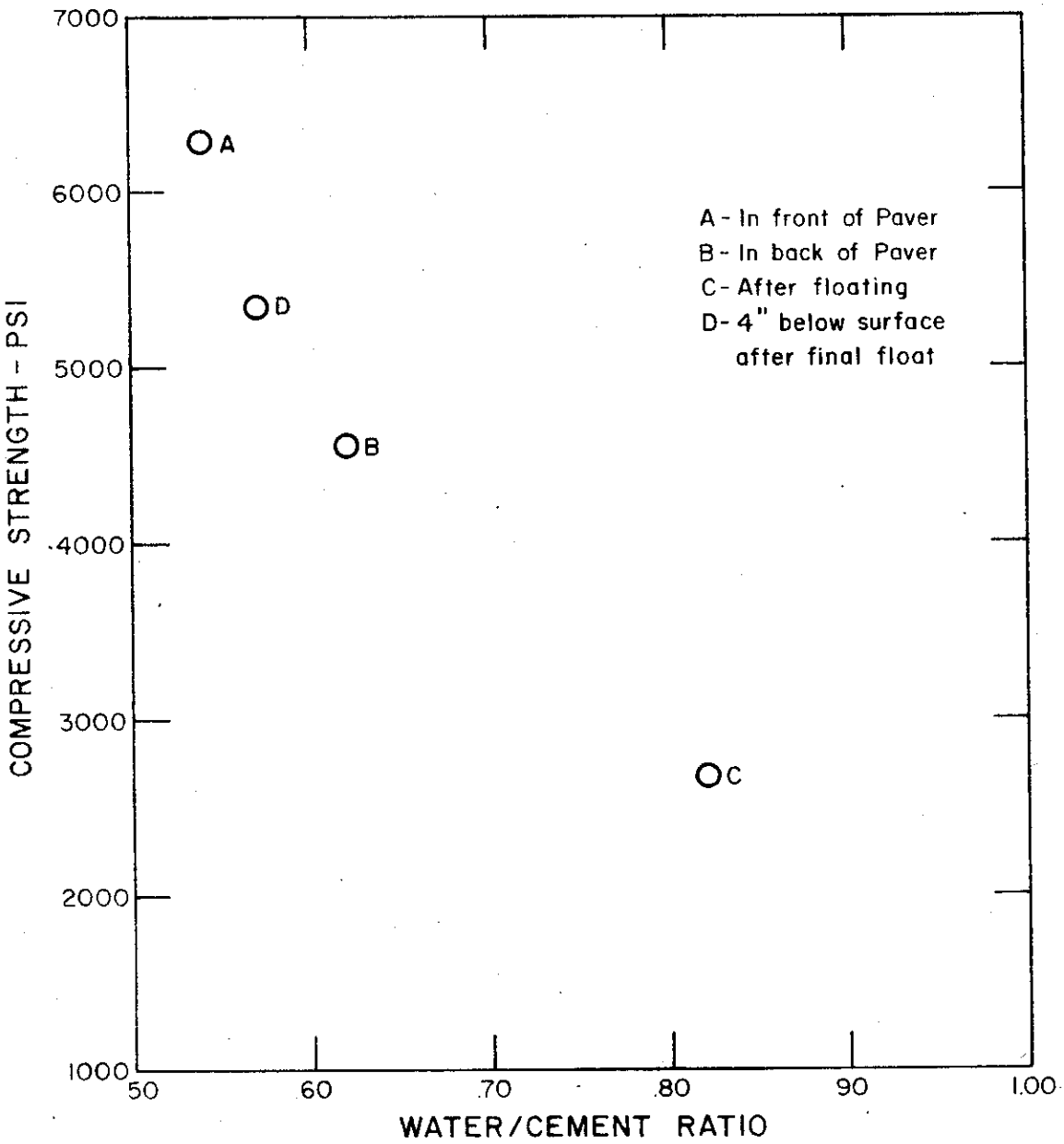

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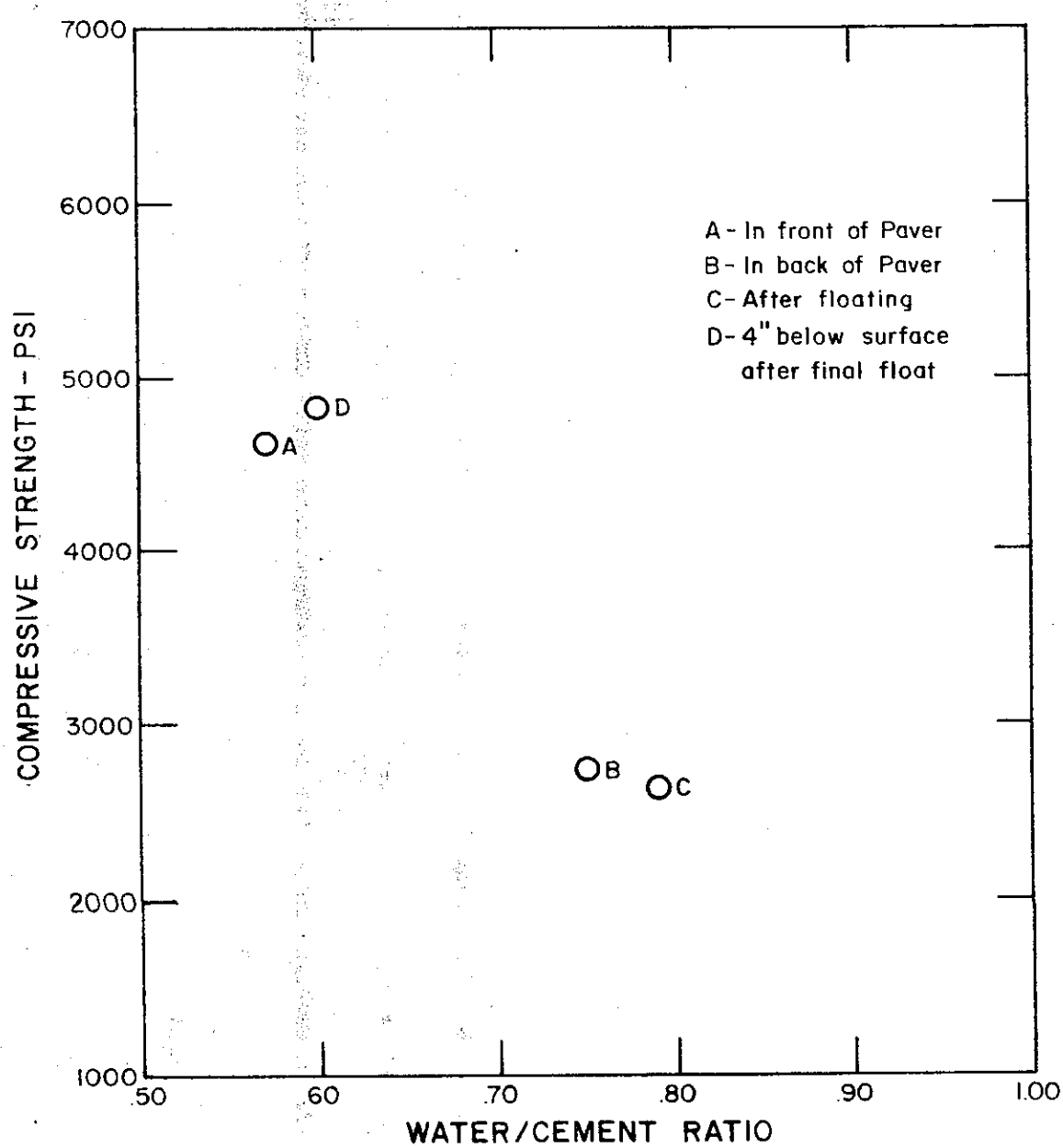
Figure 16 TEST RESULTS - WOODLAND



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4. US 101, near Ventura (Contractor A)

The Contractor had also changed his paving procedure for this project by attaching two skewed pipe floats to the rear of the paver. No further floating was done unless a small amount of hand finishing was required. Water was added at the rotating screed during the testing periods. While the "B" samples were taken right behind the paver, the two floats had already passed over the surface. The "C" samples were then taken from the surface just before texturing. Results of tests are shown in Figure 17. The "B" results show a considerable loss in strength, and the "C" results show further loss even though no additional finishing had taken place. This additional strength loss may be attributed to the fairly large amount of bleeding which had taken place and is substantiated by the higher W/C ratio measured.

5. I-210, near Pasadena (Contractor G)

The paver used on this project was the same type used on many of the other projects tested. A rotating screed was attached to the back of the paving machine and water was sprayed onto the screed constantly during paving. A mechanical pipe float was used for finishing and texturing was accomplished by brooming. During testing, no water was added at the float. Test results are shown in Figure 18. The effect of water added at the paver is readily apparent. Very little more strength was lost due to floating, however, and the W/C ratio was not significantly changed.

6. US 101, near Gilroy (Contractor E)

For this project the Contractor again used a mechanical pipe float. Although no water was added at the paver, the float

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Figure 17 TEST RESULTS - VENTURA

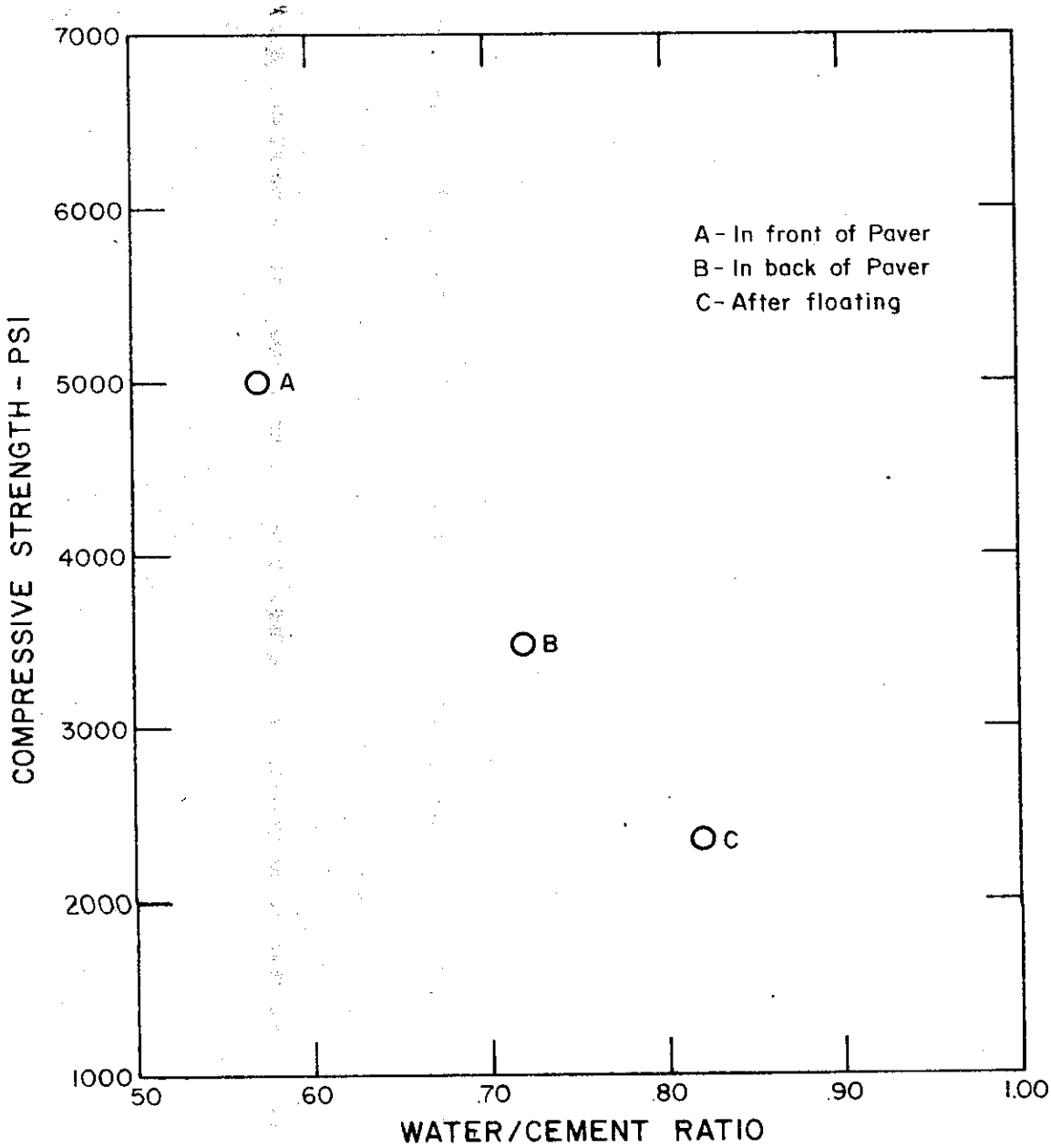

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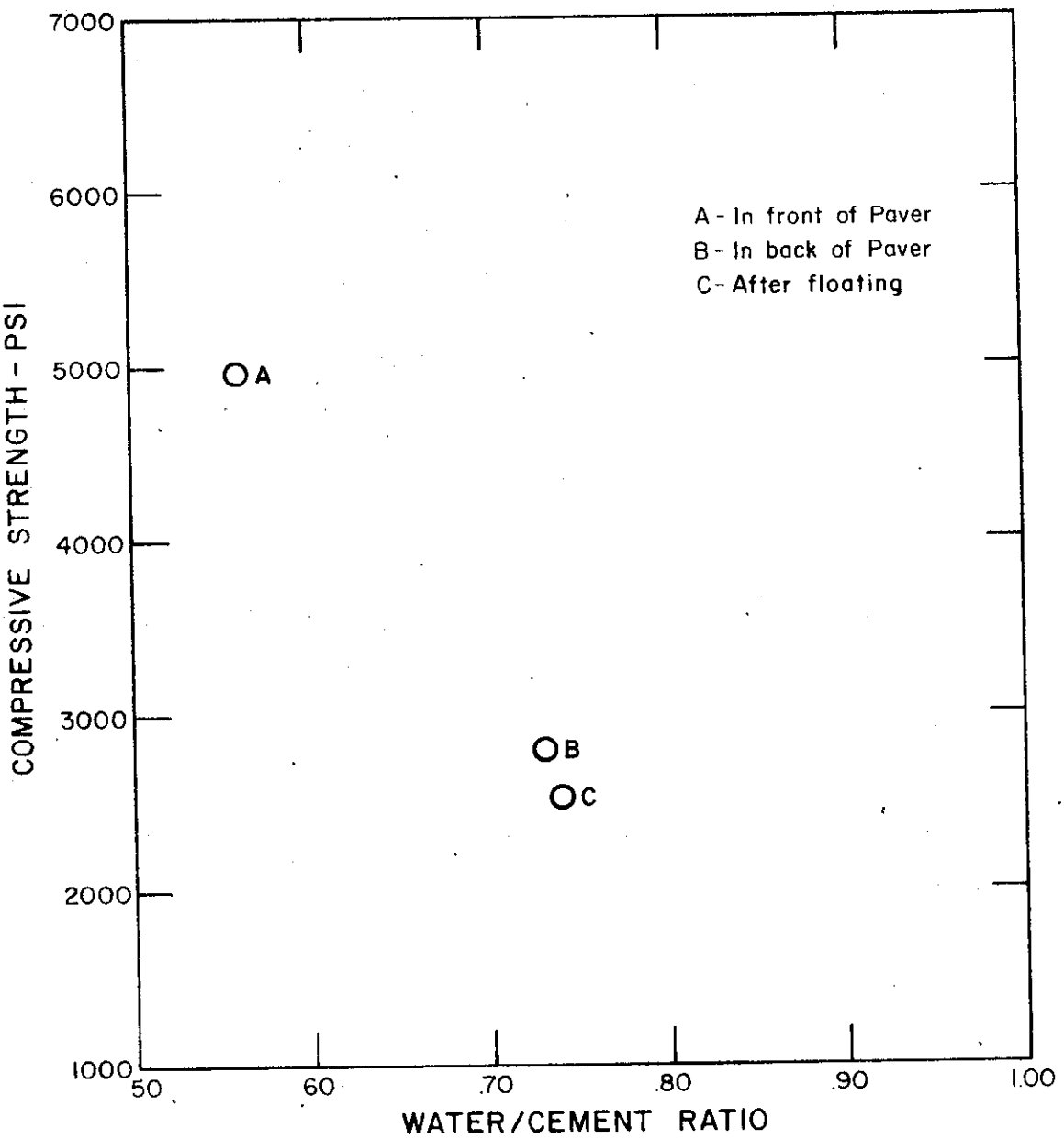
Figure 18 TEST RESULTS - PASADENA



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operator sprayed water on the surface from a handheld hose. Test results are shown in Figure 19, which again show a considerable loss in strength directly behind the paver and an unusually weak mortar after floating. This pavement will be closely watched in the future to determine surface wear and skid resistance characteristics.

D. Discussion

To present a clearer overall view of the test results, the compressive strengths of mortar samples from all 13 field tests are summarized in Table 11. These data show that mortar forming the finished surface texture has only about half the strength of the mortar from the concrete mix as delivered to the paver.

The effect of water added to the pavement surface is shown in Table 12. Whether water is added at the paver or at the float, the detrimental effects are significant. When no water was added at either point (only 2 cases), the total strength loss of the mortar was only about 26%. While two tests are not considered adequate for determining the true effect of no added water, it is reasonable to expect strength improvement if the water-cement ratio is not increased by the addition of water during finishing.

The evaluation of these field trials will continue with friction coefficients and photographs being obtained periodically.

SUMMATION

In the preceding pages, various phases of pavement construction were discussed with each phase being shown to have an important effect on the quality of the pavement surface.

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Figure 19 TEST RESULTS - GILROY

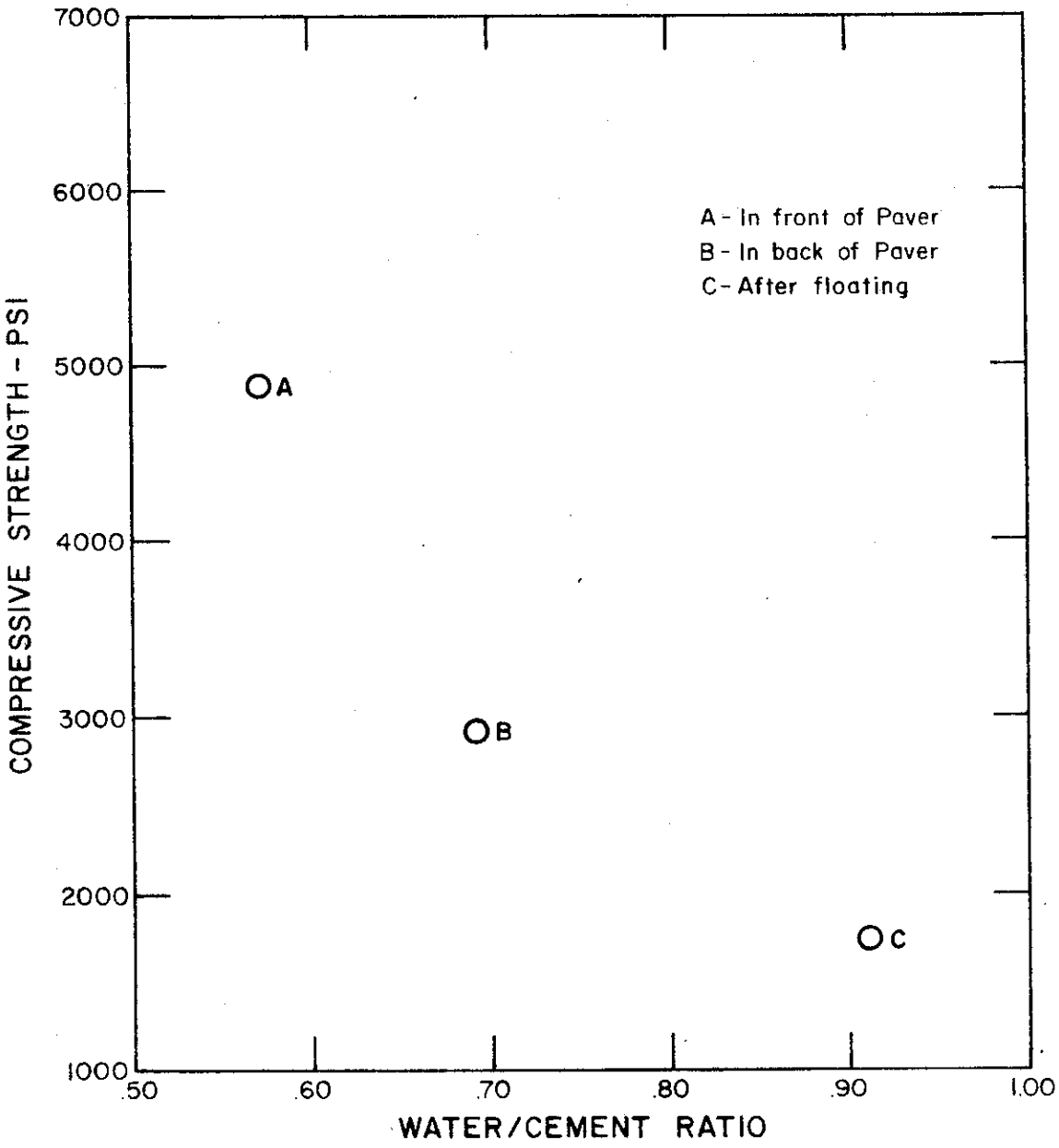

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Table 11

Summary of Compressive Strength Results

Location	Contractor	Float Passes	Water Added by Paver	Water Added by Float	Sample Location A	Sample Location B	Sample Location C
Boron	A	0	Yes	No	5460		3480
		0	Yes*	No	5340		4170
		2	Yes	No	5420		2980
Carlsbad	B	1	No	Yes	7310		3700
		3	No	Yes	7270		3110
Oceanside	C	4	Yes	No	5100	3950	3020
		4	No	Yes	5590	4030	3690
		2,4	Yes	Yes	5840	3220	3130
Sacramento	C	2	Yes	No	4930		2430
		4	Yes	No	4910		2070
		4	Yes	No	4700	2180	2010
		4	Yes	No		2440	2090
Mendota	B	1	No	Yes	4280	3570	2930
		2	No	No	4310	3660	3110
		2	No	No	4650	3780	3480
San Ardo	D	2	No	Yes	5940	4890	3850
Los Banos	E	4	Yes	No	5050	2790	3090
Weed	F	Routine	No	Yes	5250	3290	3490
San Diego	B	Routine	No	Yes	6300	4570	2690
Woodland	E	Routine	Yes	No	4650	2760	2650
Ventura	A	Routine	Yes	No	5000	3470	2340
Pasadena	G	Routine	Yes	No	4970	2820	2530
Gilroy	E	Routine	No	Yes	5900	2920	1740
Average					5330	3400	2950
Average loss of B & C Samples						36%	45%

* Water cut by one-half.

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Table 12

Effect of Added Water on Compressive Strength

Water Added by Paver	Water Added by Float	PSI A	PSI B	% Loss	PSI C	% Loss
Yes	No	5100	3950	23	3020	41
Yes	No	4700	2180	54	2010	57
Yes	No	5050	2790	45	3090	39
Yes	No	4650	2760	41	2650	43
Yes	No	5000	3470	31	2340	53
Yes	No	4970	2820	43	2530	47
Average		4910	2990	39	2610	47
No	Yes	5590	4030	28	3690	34
No	Yes	4280	3570	17	2930	32
No	Yes	5940	4890	18	3850	35
No	Yes	5250	3290	37	3490	34
No	Yes	6300	4570	27	2690	57
No	Yes	4900	2920	40	1740	64
Average		5380	3880	28	3060	43
No	No	4310	3660	15	3110	28
No	No	4650	3780	19	3480	25
Average		4480	3720	17	3290	226
Yes	Yes	5840	3220	45	3130	46

A - Mortar wet screened from concrete in front of paver.

B - Mortar scraped from surface immediately following paver.

C - Mortar scraped from surface following floating.

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With increased skid resistance standards, surface textures have been made rougher which makes curing with liquid type pigmented curing compounds more difficult. Improved formulations of curing compounds were developed and two have been adopted as standards by the State. These formulations, one with a petroleum hydrocarbon base and the other with a chlorinated rubber base, have been found to be more satisfactory than the previously used wax/resin base materials.

New methods of texturing have been tried and performance is being monitored. Two methods showing promise are (1) grooving of the fresh concrete, and (2) spreading of selected aggregate on the plastic concrete surface. Various devices for grooving have been studied and others are being considered. Also under consideration are proposals for transverse grooving of the fresh concrete, and longitudinal grooving of the hardened concrete soon after placement.

Regardless of the quality of texturing and curing, an enduring skid resistant surface is dependent on the quality of the surface mortar. Tests have shown that on the average, almost 50% of the potential mortar strength is lost during concrete placing and finishing operations. About one half of the loss appears to be unavoidable, but considerable improvement could be attained by changing finishing techniques and eliminating, or reducing the amount of, water added to the surface to aid in finishing. On the thirteen paving projects visited during this study, the "normal" paving operation included having water added at the paver or during floating, or a combination of the two. While dampening of the surface is probably needed at times, it appears that water is being added unnecessarily on many projects. (See Figures 20 through 23.)

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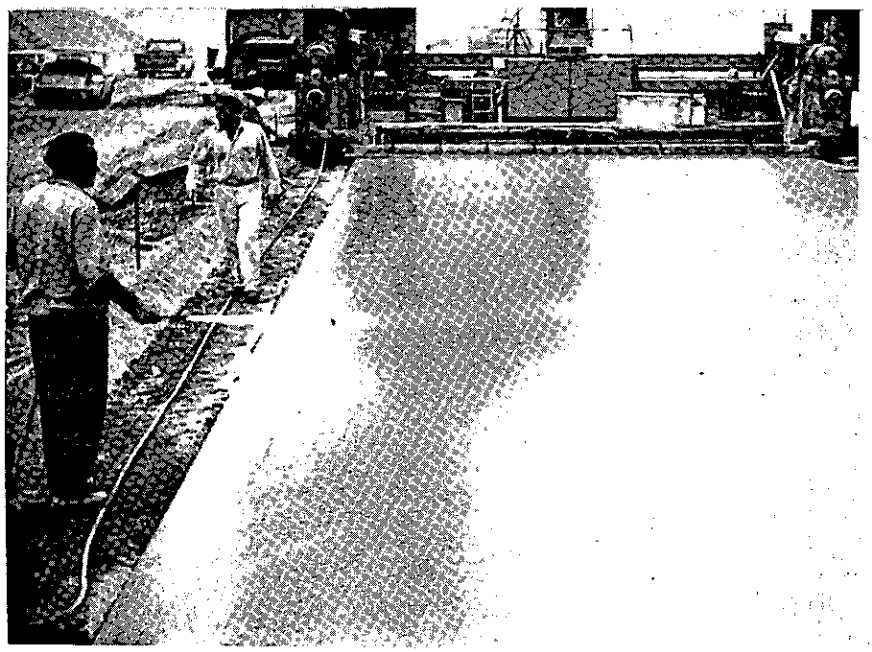

Figure 20. Spraying water on surface behind paver.

Figure 21. Water spray bars mounted on pipe float. (Broom being drug behind.)

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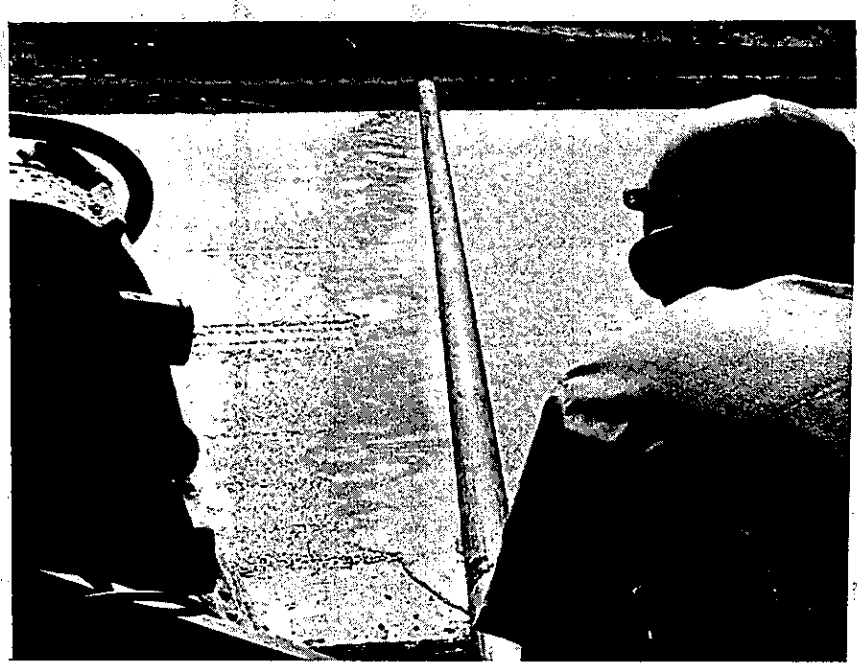

Figure 22. Excess water moved by pipe float.

Figure 23. Excess water moved by pipe float.

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By following well documented, recommended concrete construction practices, the loss in surface mortar strength could be held to a minimum. To quote from the American Concrete Institute's Manual of Concrete Practices, 1973:

> "To obtain a durable surface on unformed concrete proper procedures must be carefully followed. The concrete used should be of the lowest practical slump that can be properly consolidated, preferably by means of internal mechanical vibration. Following consolidation, the operations of screeding, floating, and first troweling should be performed in such a manner that the concrete will be worked and manipulated as little as possible in obtaining the desired result. Over-manipulation brings excessive fines and water to the top which impairs the quality of the finished surface causing such undesirable effects as checking, crazing, and dusting. For the same reason each step in the finishing operation, from the first floating to the final floating or troweling, should be delayed as long as possible and still permit the desired grade and surface smoothness to be obtained. Free water is not as likely to appear and accumulate between finishing operations if proper mix proportions and consistency are used. However, if it does accumulate, it should be removed by blotting with mats, draining, or pulling off with a loop of hose, so the surface can lose its water sheen before the next finishing operation is performed. Under no circumstances should any finishing tool be used in an area before accumulated water has been removed, nor should neat cement or mixtures of sand and cement be worked into the surface to dry such areas."

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The timing of the finishing, texturing, and curing operations is very critical. The proper time to perform each operation is dependent on so many variables that writing specifications applicable under all conditions is difficult. Perhaps a better approach would be an educational program for inspectors and concrete workers to teach the recommended practices, then insist on strict adherence to these practices.

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APPENDIX

METHOD OF TEST FOR DETERMINING THE SURFACE ABRASION RESISTANCE OF CONCRETE SPECIMENS

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METHOD OF TEST FOR DETERMINING THE SURFACE ABRASION RESISTANCE OF CONCRETE SPECIMENS

Scope

The surface abrasion test measures the ability of a concrete specimen to resist surface abrasion by impact in the presence of water.

Procedure

A. Apparatus

1. A mechanical shaker capable of agitating a mold assembly containing the test specimen, water, and steel balls, in a vertical direction at 1200 cycles per minute with a 1-inch stroke. (Drawings are available from the Office of Transportation Laboratory.)

2. 1 - steel test mold, 4 inches ID by 5 inches high, fitted with a watertight base and cover. A 1/8" steel ring, triangular in cross-section and inserted to form a lip, encircles the mold interior 2 inches above the bottom and combines with the base to hold the sample in place and protect the vulnerable edges of the specimen.

3. 8 steel ball bearings, 13/32-inch diameter, weighing 4.5 grams each.

4. 1 - 200 ml graduated cylinder.

5. Balance sensitive to 1 gram.

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Test for Determining the Surface
Abrasion Resistance of Concrete
or Mortar Specimens

B. Specimens

The test specimens shall be cylindrical in shape, 4 inches in diameter and 2 inches high, and may be either cores cut from hardened concrete or specimens molded from concrete. They shall be soaked in water for a minimum of 24 hours prior to testing.

C. Test Procedure

1. Surface dry the specimen, weigh, and record weight to the nearest gram.

2. Place specimen in the test mold with the surface to be tested facing up. Place the mold with specimen on the base and add 8 steel ball bearings and 200 ml of water. Attach the cover making sure rubber gaskets are in place and clamp the assembly to the mechanical shaker.

3. Agitate the assembly at 1200 $\pm$ 10 CPM for 20 seconds and remove from the mechanical shaker.

4. Remove the specimen from the test mold. Flush off the abraded material, wash the specimen, surface dry, weigh, and record to the nearest gram.

5. Repeat Steps 2, 3, and 4 for 40 additional seconds and two additional minutes. The three readings are taken at total times of 20 seconds, 1 minute and 3 minutes.

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Test for Determining the Surface
Abrasion Resistance of Concrete
or Mortar Specimens

D. Calculations

The abrasion loss in grams is calculated by subtracting the weight of the surface dry specimen after the test from the weight of the surface dry specimen before test.

Reporting of Results

Report the amount of abrasion loss in grams. Record the loss after 20 seconds, 1 minute, and 3 minutes. The age of the concrete shall be included in the report.

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