REPORT NO. FHWA-CA-TL-78-14

SURFACE TEXTURES FOR PCC PAVEMENTS

FINAL REPORT
APRIL 1978

Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

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This study was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT
The purpose of this study was to develop methods of obtaining more durable and skid resistance PCC pavement surfaces.

This report is divided into two parts as follows:

I. Surface Texture Measurement Devices

Several texture measurement methods were field tested and compared, and the merits of each method are discussed.

II. Surface Texturing Methods

Different texturing procedures were tried on several ongoing projects. The methods were:

1) Aggregate broadcast on pavement surface.
2) Transverse texture using a) a steel ribbed grooving plate, b) a nylon bristle broom, and c) several steel tine devices with various spacings and tine lengths.
3) Longitudinal texture with steel tines.

As a result of the tests, longitudinal texturing with steel tines has been adopted as a standard procedure.

17. KEY WORDS
Concrete pavement, surface texture, surface texture measurement, skid resistance.

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

April 1978

FHWA No. D-3-49
TL No. 635293

Mr C. E. Forbes
Chief Engineer

Dear Sir:

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

SURFACE TEXTURES FOR PCC PAVEMENTS

Study made by . . . . Roadbed & Concrete Branch

Under the Supervision of . . . . D. L. Spellman

Principal Investigator . . . . J. H. Woodstrom

Co-Investigator . . . . B. F. Neal

Report Prepared by . . . . D. E. Peck and B. F. Neal

Very truly yours,

George A. Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

BFN:lb

ACKNOWLEDGEMENTS

The authors would like to thank the many contractors and resident engineers for their cooperation and assistance in conducting the field work. Considerable contributions were also made by R. J. Spring and S. N. Bailey of the Office of Transportation Laboratory, and L. S. Spickelmire of the Office of Construction.

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INTRODUCTION

Portland cement concrete pavements in California often show a significant loss in initial surface texture and skid resistance qualities within a few years after the pavements are opened to traffic. This loss usually results from a direct reduction in both the macro-texture and micro-texture of the surface. As a result of this change in texture, the surface loses its ability to provide good skid resistance, as well as adequate channels of escape for surface water during wet weather.

Once the pavement surface has become a potential wet weather hazard, it becomes necessary to restore the pavement to a safe riding condition. This has been accomplished in recent years by constructing longitudinal grooves in the pavement surface with the aid of diamond grooving equipment. This practice of grooving has proven very successful in reducing wet weather accidents.

The constant concern for the traveling public on PCC roadways, and economic factors involved in restoring the roadways to a safe condition, has led to the investigation of new methods of initially texturing of roadway surfaces to assure adequate and long lasting texture.

Part I of this report deals with various surface texture measurement devices. While searching for more durable and better skid resistant pavement surfaces, it became evident that there was a need for determining texture depth and wear rate. Initial texture depth when compared to subsequent texture depth would give a means of determining durability. Field tests of several types of texture measurement devices were conducted and comparisons of advantages and disadvantages appear in this report.

Part II deals with surface texturing methods. One method considered for providing a satisfactory texture was broadcasting of various types of aggregate on the surface of fresh concrete. It was assumed that lightweight aggregate, for instance, much of which is vesicular by nature, would continue to provide good skid resistance even while wearing down. Early trials of this method, using hand broadcasting, were discussed in a report titled "PCC Pavement Texture Quality Investigation" (1). The trials reported herein were made because of promising results of earlier tests.

Transverse grooving of plastic concrete was also evaluated. Steel tines of various cross section, length, and spacing, and a ribbed metal grooving plate were used experimentally to provide the texture.

Earlier experiments with steel tine surface textures have proved promising as indicated in reports by others (2,3). It has also stirred controversy with respect to increased noise levels. This report also deals with comparative noise level studies of different types of transverse texture.

Another texture method investigated was longitudinal texturing of fresh concrete with steel tines. Different degrees of texture were obtained by varying the angle of incidence and tine configuration.

CONCLUSIONS

For measuring average groove depths and the wear rate of textured surfaces, the sand patch test and texture profiling device were considered the most useful methods of all those tested. These tests, along with skid resistance measurements, provide a means of evaluating PCC pavement texture life.

The method of texturing considered the most desirable, at least at this time is that created by using an initial drag with burlap or broom followed by a steel tine device to form deeper grooves.

Skid testing on the San Diego and Geyserville projects indicated good skid resistance was obtained with the steel tines. The deeper grooves and wider land areas can reasonably be expected to last longer than a broomed surface with very narrow lands. Based on these observations, California's long experience with longitudinal texturing, and the proven accident reduction by longitudinal grooving, longitudinal tine texturing was adopted.

Evaluation of the durability of both longitudinal and transverse tine texturing, and of broadcast aggregate texturing should be continued. It is proposed to do this under another project.

IMPLEMENTATION

As a result of this research, longitudinal texturing with initial burlap or broom drag, followed by a steel tine comb device to impart deeper grooves, has been adopted as a standard on PCC paving projects. The method has been implemented on several projects by Contract Change Order and is now part of the Standard Specifications.

PART I SURFACE TEXTURE MEASUREMENT DEVICES

A basic problem related to PCC pavement surfaces is that although the surface texture is constructed in such a way as to meet present skid resistance specifications, there is no specific requirement as to the depth of such texture. The result is that some pavements do not have sufficient depth to the texture to assure adequate channels of escape for water during wet weather driving, or to insure long life. Once the surface loses some of its texture as a result of traffic wear, it may become a safety hazard during wet weather.

Procedure

To evaluate various methods of measuring texture depth, a series of tests were made on a local PCC pavement. A section of pavement which contained a heavier than normal broom texture was selected as a test area. All tests were conducted within the same 12- x 24-inch (300 x 600 mm) area.

Individual tests were conducted using the following eight Techniques:

1. Stereo Photography
2. Texture Profilometer
3. Resin Casting
4. Clay Casting
5. Sand Patch Test
6. Putty Impression Test
7. Outflow Meter Test
8. California Portable Skid Tester

Tests were conducted a total of four times with each device as follows:

A. On initial PCC texture.

B. On texture after abrading surface with a carborundum disk.

C. After a second abrading.

D. After a third abrading.

Evaluation of the different texture measuring devices included the advantages and disadvantages, as well as the potential application and cost for each.

Stereo Photography

The objective of this technique is to obtain "line" profiles of the surface texture. A pair of photographs are taken of the surface by use of two cameras positioned a set distance apart. By a photogrametric process, it is then possible to construct a profile of the surface texture between two reference points located in the pavement. See Figure 1 for example of profile construction.

Advantages

1. Results in a permanent record of the texture.
2. Can be used to compare with future profiles in determining wear characteristics of the texture.
3. Device is portable and photographs can be obtained quickly.
4. Other than the reference points, requires little preparation.

PROFILE CONSTRUCTED FROM STEREO PHOTOGRAPHS

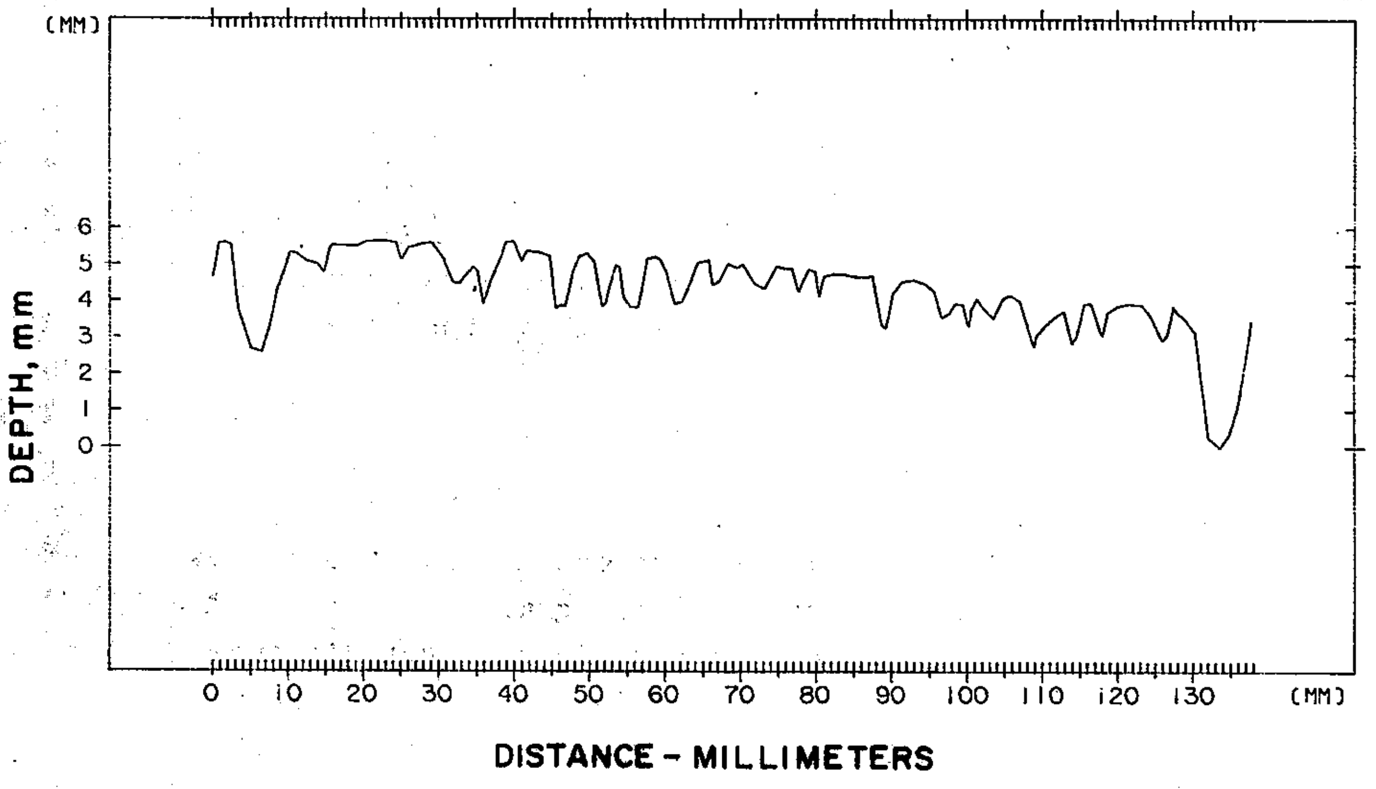


Figure 1

Disadvantages

1. Represents only a 6x6-inch (150 x 150 mm) segment of roadway texture.
2. Does not give results directly at time of test.
3. Requires lane closure.

Cost

Cost of evaluating the photographs is approximately $50 per site. This does not include the cost of the film, etc., or the cost for the operator while taking the photographs.

Application

Could be effective as a research tool.

Texture Profilometer

The texture profilometer is a device used to obtain a magnified line profile of the texture of PCC pavements (see Figure 2). The device is positioned in place by locating its three legs in pre-drilled holes in the pavement surface. This provides a reference location for the test and allows for future tests along the same profile line. Once in position, a pointer is "traversed" along the surface of the texture (see Figure 3). The pointer, through the action of a hinge and lever attached to a recording pen, transmits an expanded line approximate reproduction of the surface texture (see Figure 4).

Advantages

1. Gives a direct indication of the profile at time of test.
2. Results in a permanent record of the texture.
3. Can be used to compare with future profiles in determining the wear rate of the texture.
4. Gives an expanded vertical scale of the texture.
5. Portable.

Figure 2 - Texture Profilometer.

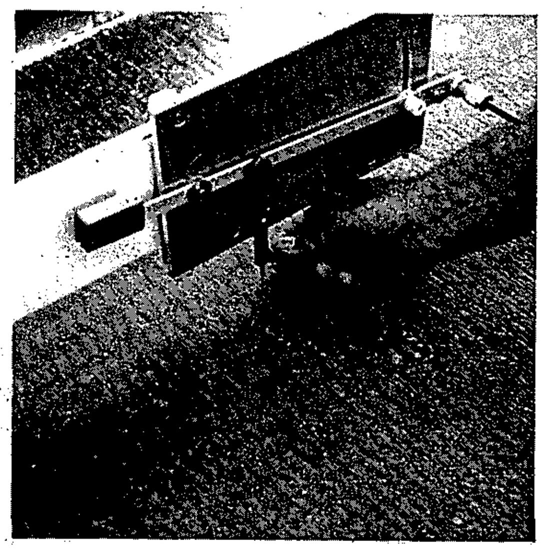
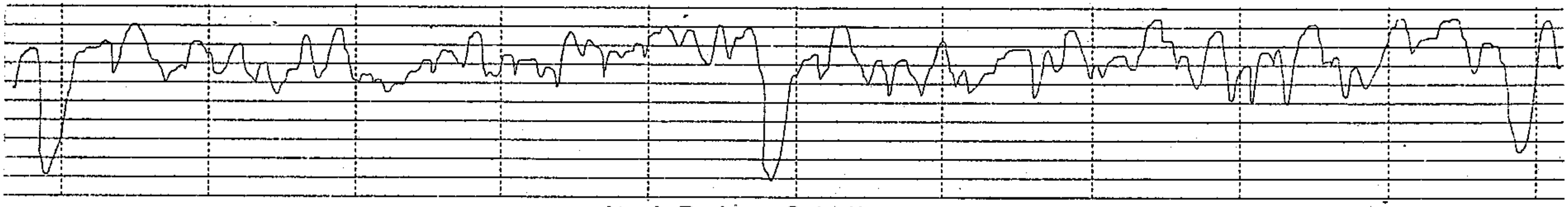
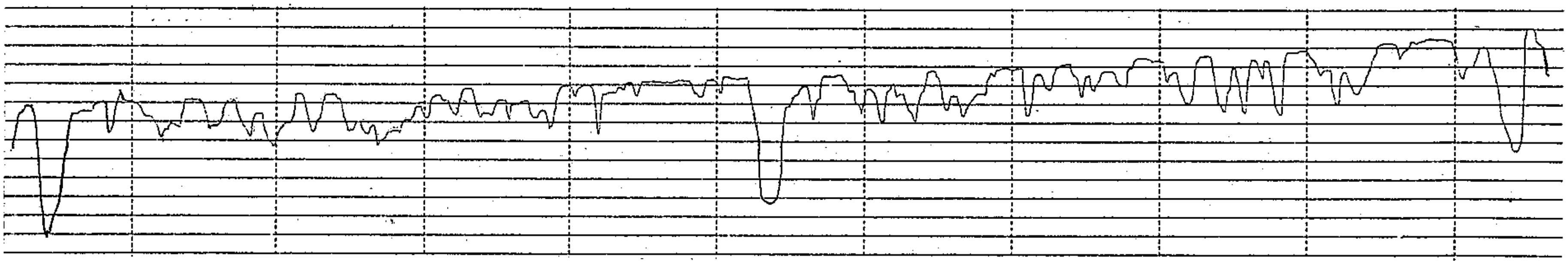


Figure 3 - Texture Profile Being Recorded.

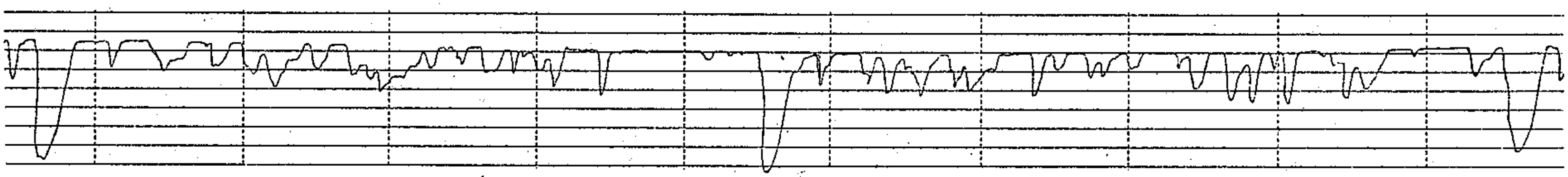
TEXTURE PROFILOMETER GRAPHS



No. 1 Before Grinding



No. 2 After 1st Grinding



No. 3 After 2nd Grinding

No. 4 After 3rd Grinding

Scale: H = 1:1
V = 5:1

Figure 4

Disadvantages

1. Requires careful manual movement of the pointer in contact with the pavement texture.
2. Results are subject to errors caused by small amounts of dust or sand in the texture.
3. Requires lane closure.

Cost

Cost per test is minimal other than the operator's cost. Once legs are located in the drilled holes, test can be completed in approximately 15 minutes.

Application

1. Could be effective as a research tool to aid in determining the rate of wear for surface texture.
2. Could possibly be used in conjunction with the specifications to require a minimum texture depth.

Resin Casting

The resin casting procedure is a process by which a hardened negative impression of the surface texture can be obtained in the field. A wooden frame with an opening of 4 x 24 inches (100 x 600 mm) is first secured to the pavement over the desired test area (see Figures 5 and 6). This is accomplished by applying a bead of "synthetic putty" between the frame and the roadway. A release agent is then applied to the inside of the form as well as the textured surface.

The resin casting material consists of the following:

1. 1 quart (946 ml) surfacing polyester laminating resin
2. 250 ml of Cabosil
3. 80 ml of Saniticizer (711)
4. 0.5 oz. (15 ml) of catalyst

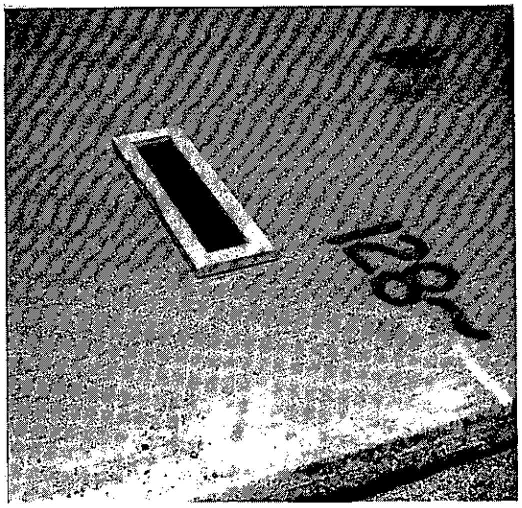


Figure 5 - Resin Casting.

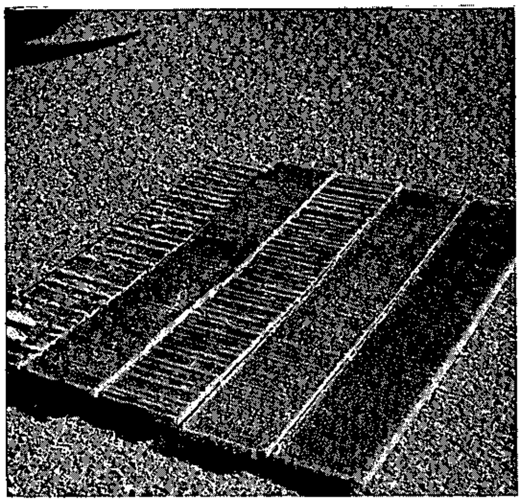


Figure 6 - Results of Several Different Texture Types, Note Spalled Concrete in Left Casting.

Items 1, 2, and 3 can be premixed. Item 4 cannot be added until just before making the casting.

Once the catalyst is added and mixed, the material is placed into the wooden form. Approximately 15-30 minutes later (depending on the temperature) the hardened casting of the surface can be removed.

Advantages

1. This process also results in a permanent record of the texture.
2. Can be used to compare with other castings at a later date.
3. Process is portable.
4. The field negative can be made into a positive casting in the laboratory.

Disadvantages

1. Difficult to transport necessary quantities of material to make a large number of castings.
2. Material shrinks slightly when curing.
3. Castings have an unpleasant odor and should be stored in a ventilated area while transporting.
4. Difficult to obtain castings on roadways with high superelevations.
5. Pavement must be dry.
6. Texture casting is negative.
7. Requires lane closure.
8. May spall concrete upon removal from deeper grooved surfaces (see Figure 6).

Cost

Material cost per test is about $3.00 per casting. Operator and traffic control costs are additional.

Application

Might be useful on a limited basis as a research tool.

Clay Casting

The clay casting procedure is a technique whereby a clay material is used to obtain a negative impression of the pavement surface. Prior to making the impression, a mold release agent is applied to the pavement surface to prevent sticking. Once the mold is made, the material is frozen by external means and can be easily removed. Positive castings can later be made after refreezing in the laboratory.

Advantages

1. Equipment is portable.
2. Clay is not affected by moisture on the pavement.

Disadvantages

1. Clay not easily worked at temperatures below 70°F (21°C).
2. Requires a lane closure.
3. Test area is only 4 inches (100 mm) in diameter.

Cost

The equipment and materials are inexpensive; less than $1.00 per test.

Application

1. Could be used as a research tool, possibly in conjunction with the Texture Profilometer.

Sand Patch Test

The sand patch test is a method of determining the average depth of the PCC surface texture. A known volume of sand is spread on the test surface with a rubber disk. The sand is spread into a circular patch with the surface depressions filled to the level of the peaks (see Figures 7 and 8). The diameter is measured at four or more equally spaced locations and using a conversion chart the average diameter is converted into average texture depth.

Advantages

1. Easy to conduct.
2. Rapid and portable.

Disadvantages

1. Test cannot be made in heavy wind.
2. Requires lane closure.

Cost

Materials cost is minimal.

Application

Could be incorporated into specifications in conjunction with skid resistance requirements.

Putty Impression Test

The putty impression method works on basically the same principle as the sand patch test. A known weight of silicone putty commonly called "Silly Putty" is formed into an approximate sphere and placed on the pavement surface. A recessed metal plate is placed over the sphere so that the sphere is in the center of the recess.

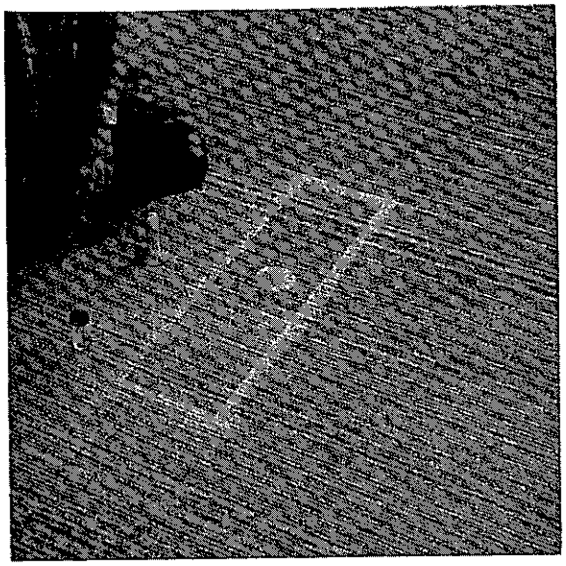


Figure 7 - Sand Patch Test Apparatus.

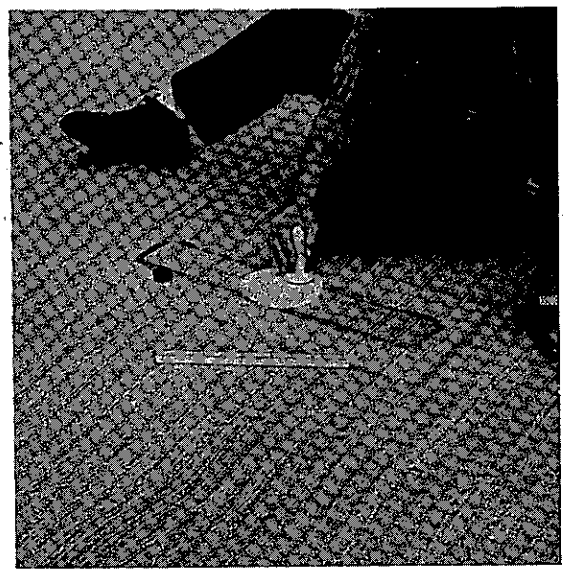


Figure 8 - Sand Patch Test Being Performed.

The plate is pressed firmly against the pavement surface. An "average diameter" value is obtained by measuring the flattened sphere. The average diameter (D) is then converted to average texture depth (T_p) by the Formula $T_p = 1/D^2 - 0.0625$

Advantages

1. Easy to conduct.
2. Rapid and portable.

Disadvantages

1. On fairly smooth surfaces, it is very difficult to apply sufficient force to obtain contact between the backing ring and the pavement.
2. Material becomes contaminated with fine sand and dust.
3. Requires lane closure.
4. Results in a negative cast.

Cost

Cost of the putty is approximately $1.00 per test.

Application

Could be incorporated into specifications and used in conjunction with skid resistance requirements, but is not considered as accurate as the sand patch test.

Outflow Meter Test

The Outflow Meter test is based on the theory that the deeper the texture, the faster a given volume of water will escape from under a rubber gasket which is in contact with the texture.

Advantages

1. Test is rapid.
2. Test can be conducted when pavement is wet.

Disadvantages

1. For very rough textures, a large quantity of water is required for each test.
2. Repeatability is difficult especially if device is not placed precisely over the same test area or texture includes scattered high spots which are much higher than the average surrounding area.
3. Requires lane closure.

Cost

Operator cost only.

Application

Although the tests reported here indicate relatively good correlation with texture depth, subsequent tests show wide variability with deeper textures such as that formed by wire tines. It is therefore not considered sufficiently accurate for measuring PCC texture depths.

California Portable Skid Tester (TM No. Calif. 342)

This test is designed to give a measure of the friction resistance of wetted roadway surfaces (see Figure 9). Skid resistance is not necessarily a measure of texture depth, and tests were made only for informational and comparison purposes. Table 1 and Figure 10 show results from some of these tests.

From the total of 8 tests to characterize pavement texture three of the methods were adopted for research use in evaluating texture depth and skid resistance. These are (1) texture profilometer, (2) sand patch test, and (3) portable skid tester.

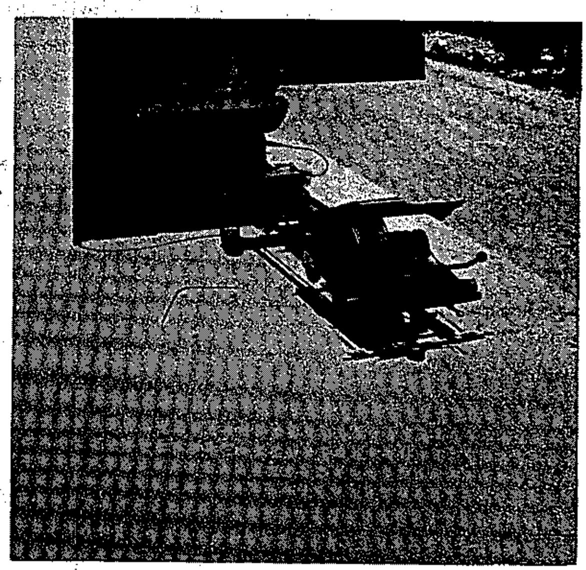


Figure 9 - California Portable Skid Tester.

TABLE 1

COMPARISON OF

SAND PATCH; PUTTY IMPRESSION; OUTFLOW METER; SKID NUBMER

Test No.	Sand Patch		Putty Impression		Outflow Meter	
	Diameter, Inches	Depth of Texture, Inches	Diameters, Inches	Depth of Texture, Inches	Time, Seconds	Skid Number
1-A	6.4	0.047	3.0	0.049	3.4	Over 50
1-B	6.3	0.048	3.0	0.049		
2-A	7.8	0.031	3.2	0.035	10.7	43
2-B	7.8	0.031	3.2	0.035		
3-A	9.4	0.022	3.4	0.024	19.3	35
3-B	9.4	0.022	3.4	0.024		
4-A	10.8	0.016	3.4	0.024	27.3	29
4-B	10.5	0.017	3.4	0.024		

Note: Test Nos. are:
1. Original texture.
2. After abrading one time.
3. After abrading two times.
4. After abrading three times.

Test letters A and B are replications.

Skid Number based on Test Method No. Calif. 342.

1 inch = 25.4 mm

TEXTURE DEPTH VS COEFFICIENT OF FRICTION

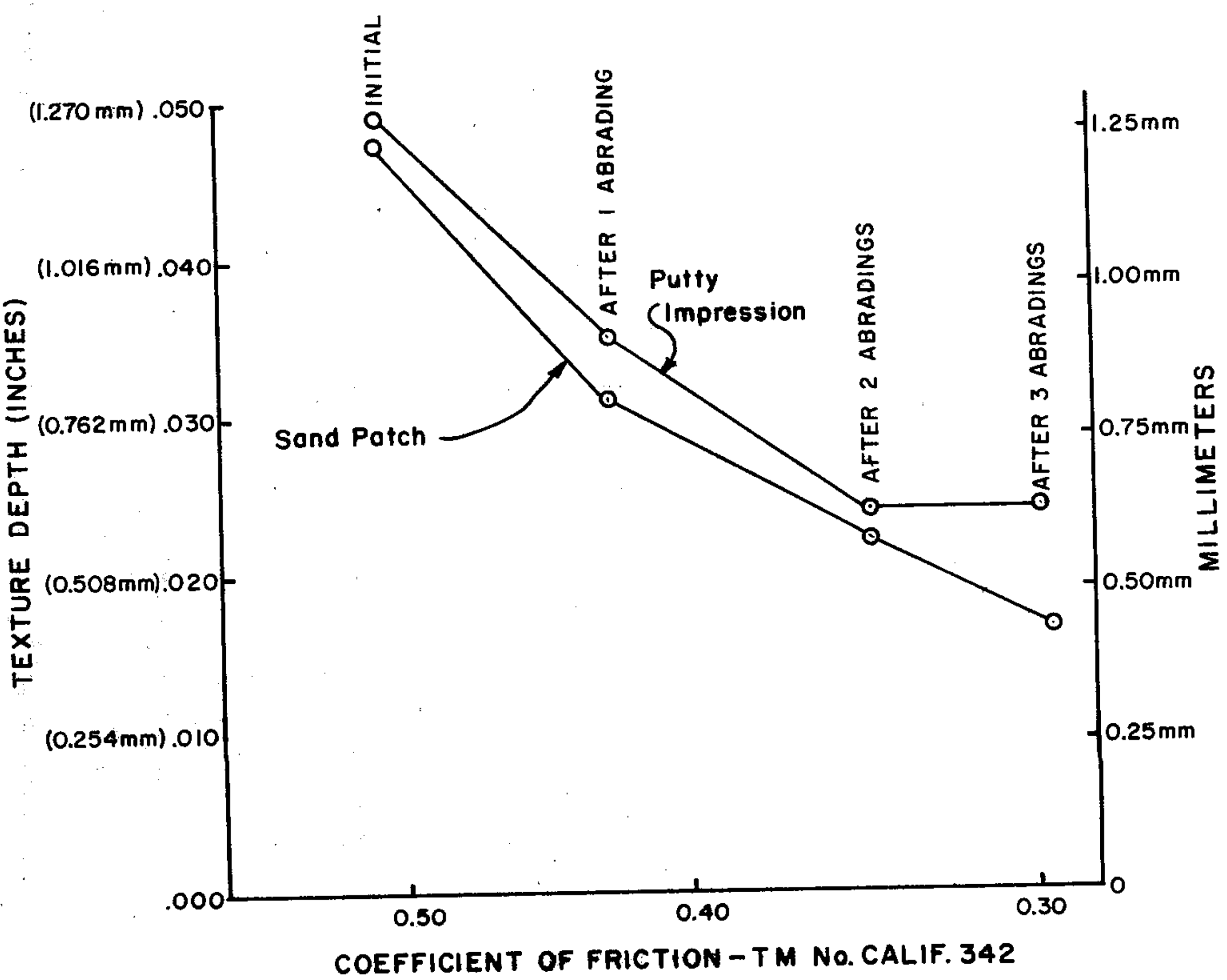


Figure 10

PART II SURFACE TEXTURING METHODS

WEST COVINA

The project selected for broadcast aggregate was located on Route I-10 near the City of West Covina in Los Angeles County. This particular project had two features which were considered advantageous to this research. First, it was a widening contract which allowed all of the test sections to be constructed in the new 12-foot (3.65 m) wide outer lane. Second, the profile grade in the location of the test sections ranged from -3.5% to +6.0%. The grade, plus the fact that this particular lane would receive heavy truck traffic, would help to accelerate wearing of the experimental surface texturing.

Paving Procedure

The contractor used a modified CMI slipform paver equipped with a rotating screed for placement of the concrete. A spray bar attached above the rotating screed gave the paving operator the ability to apply additional water to the pavement surface during the paving operation. A vaned spreader, located behind the rotating screed was used to apply the aggregate to the surface of the pavement on the specified sections (see Figure 11). The aggregate was imbedded into the surface with the aid of a roller mounted behind the spreader. A pan float and vibrator located behind the roller helped smooth the surface and work additional mortar up around the aggregate particles.

The finishing float consisted of a pipe float which at first was hand pulled, but later attached directly to the paver by ropes and pulled at approximately a 30° skew. In addition, several finishers were working with hand floats along both

SCHEMATIC OF VANED SPREADER AND HOPPER USED TO APPLY AGGREGATE TO SURFACE WITH ROLLER TO IMBED AGGREGATE

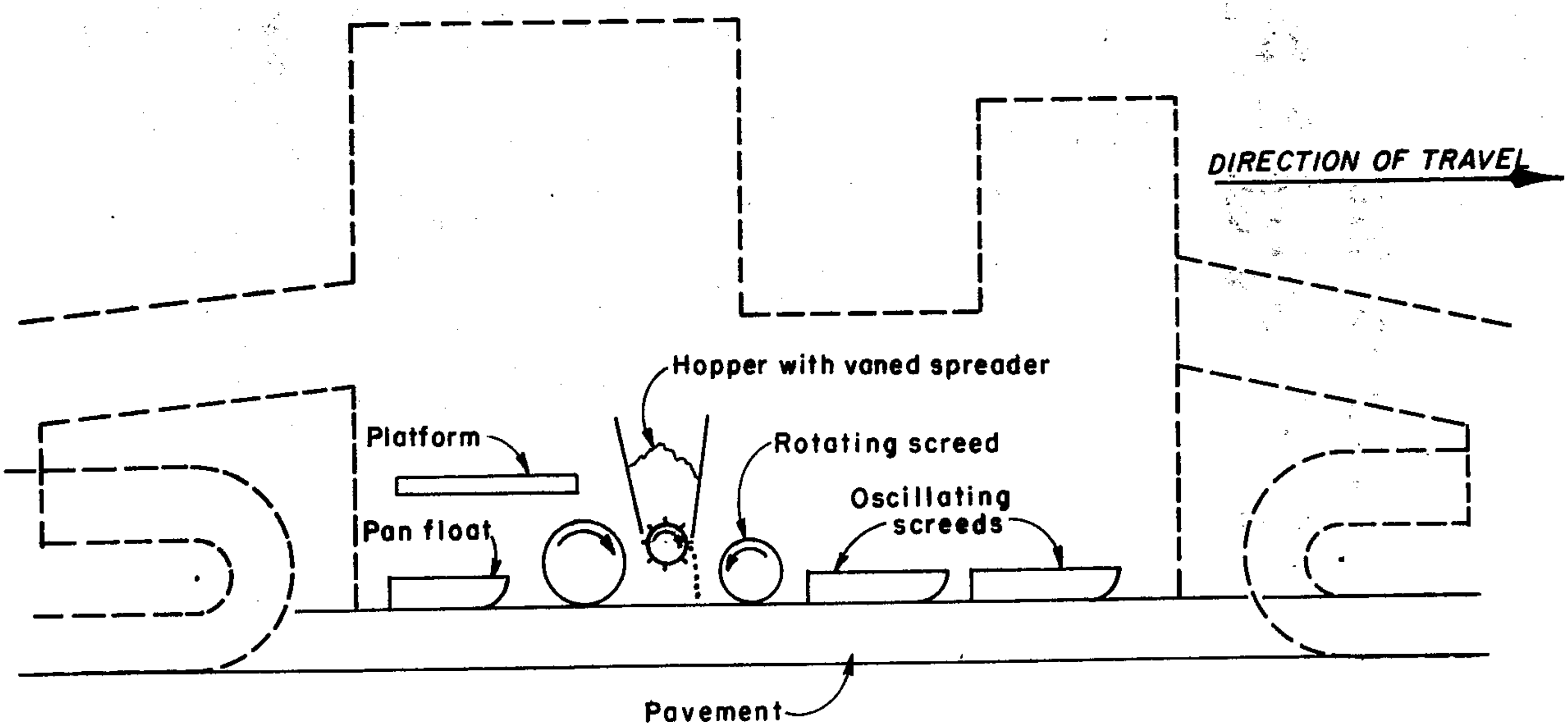


Figure 11

edges of the slab. Additional water was applied by the finishing crew during the finishing operation.

The final phase of the paving operation was the texturing and curing of the pavement. The texturing was accomplished by the use of a burlap drag attached to a transverse bar located on the front of the curing machine. Texturing of the pavement was usually accomplished with three passes of the burlap drag, two in the direction of paving and one in the opposite direction. A resin base curing compound was applied during the final pass of the texturing curing machine.

Locations

The first section of roadway placed was a control section which represented the contractor's normal paving operation (see Table 2 for section locations). Although the fresh concrete had an average initial penetration of 1-1/4-in. (32 mm) the paving operator was continually adding additional water to the surface with the aid of the spray bar located in front of the rotating screed. As a result, the surface of the pavement following the slipform paver appeared very wet. This was substantiated by the water-cement ratio results.

Following this initial section, a second was placed without additional water being applied by the paving machine. During this operation, a marked visual difference was noticed in the surface moisture; however, no apparent problems were encountered by either the paver or finisher. Some slight surface voids were noticed, but nothing of any great significance (Sample Series 2).

The next length of pavement was another control (Sample Series 3) and was followed by three sections utilizing different aggregates for surface texturing (Sample Series 4, 5, and 6). These latter sections were:

TABLE 2

LOCATION OF SPECIAL TEST SECTIONS
FOR PAVEMENT AT WEST COVINA, ROUTE 10
(KELLOG HILL)

	Section	Station	Distance, Feet
1.	Normal Paving Operation (Control)	247+07 to 260+00	1293
2.	No Water Added by Paver	260+00 to 268+50	850
3.	Normal Paving Operation (Control)	268+50 to 270+00	150
4.	Ramp Area (Omit)	270+00 to 277+00	700
5.	Slag	277+00 to 283+50	650
6.	Crushed Gravel	283+50 to 293+50	1000
7.	Lightweight	293+50 to 304+50	1100
8.	Normal Paving Operation (Control)	304+50 to 310+00	550
9.	Ramp Area (Omit)	310+00 to 328+00	1800
10.	Normal Paving Operation	328+00 to 335+00	700
11.	Normal Paving Operation	335+00 to 340+00	500

Note: 1 ft. = .3048 m

1. 650 feet (198 m) with lightweight blast furnace slag aggregate.

2. 1000 feet (305 m) with crushed material.

3. 1100 feet (335 m) with lighweight aggregate (see Table 3 for gradings).

All of the aggregates were applied in the same manner and at the same rate by the use of the vaned spreader and hopper. The individual aggregate particles were imbedded into the roadway surface by a steel roller which was set to rotate at the same speed as that of the paver.

The procedure used to apply the aggregate to the surface worked very well. The rate of application appeared to be somewhat heavy (1/6 cu.ft./sq.yd.) (5.6×10^{-3} m^3/m^2). As a result, some of the aggregate did not receive a sufficient amount of grout initially to give a good coating to the particles (see Figures 12 and 13). However, during the finishing operation, the pipe float was able to work up a sufficient supply of grout to bond the aggregate to the surface.

The contractor was adding water to the rotating screed during application of the aggregates. This did not appear to create any serious problems on the high side of the roadway, but did cause an excessive amount of water to migrate to the low side resulting in some of the mortar being washed from around the aggregate. In these and other isolated areas, hand finishing was required.

The texturing procedure continued by passing a burlap drag over the surface. Some of the aggregate was loosened, creating a popcorn effect. This might have been avoided if the surface had been less wet or if the pipe float had made additional passes.

TABLE 3

AGGREGATE USED FOR
WEST COVINA TEST SECTIONS

Lightweight Blast Furnace Slag
International Mill Service
Fontana, California

5/8-inch Material

Sieve Size	% Passing
3/4 inch	100
1/2 "	96
3/8 "	46
No. 4	5
No. 8	0

Crushed Aggregate
Consolidated Rock Company
Los Angeles, California

1/2-inch Crushed Aggregate

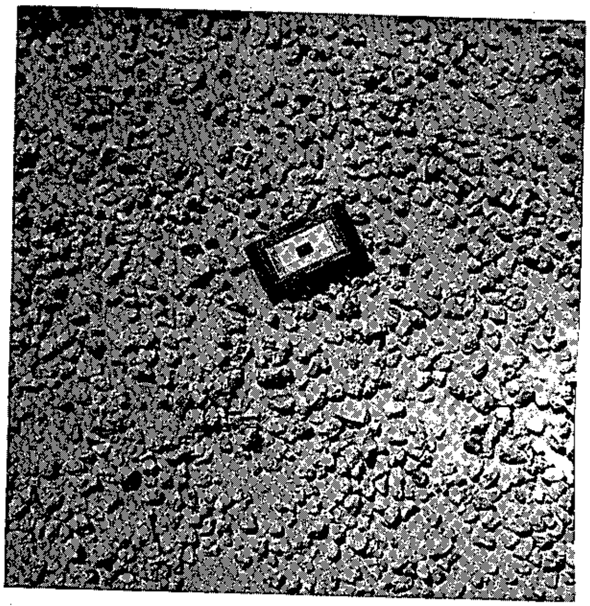
Sieve Size	% Passing
3/4 inch	100
1/2 "	98
3/8 "	45
1/4 "	7
No. 4	4
No. 8	0

Lightweight Aggregate
Ridgelite - Rocklite
Lightweight Processing Co.
Los Angeles, California

1/2-inch Material

Sieve Size	% Passing
3/4 inch	100
1/2 "	97
3/8 "	55
1/4 "	5
No. 4	1
No. 8	0

Note: 1 inch = 25.4 mm



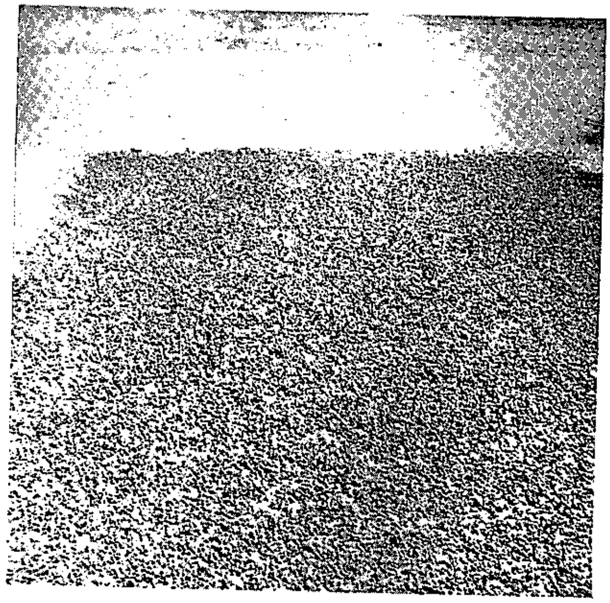


Figure 12

Figure 13

Closeup and overall view
of aggregate application
(1/6 cu.ft./sq.yd.)
($5.6x10^{-3}m^3/m^2$).

A third "control" was added following the three aggregate test sections (Sample Series 7).

Testing Procedure

During placement of the concrete, mortar samples were obtained as follows:

Sample "A" was wet screened from the fresh concrete located in front of the slipform paver. This sample represented the potential mortar strength of the concrete.

Sample "B" was taken from the surface of the PCC pavement immediately following the paver and at the same location as the "A" sample.

Sample "C" was taken from the surface adjacent to where the "B" sample was taken, after floating, and just prior to texturing.

At each sampling location, the following test program was performed:

1. A sample of mortar, passing the No. 4 (4.75 mm) sieve, was collected. The amount of this sample was sufficient to produce two 150-gm. samples for titration tests, one 1000-gm. sample for moisture determination, one set of three 2 x 2 x 2-in. (50 x 50 x 50 mm) mortar cubes, and two 4-in. (100 mm) diameter by 2-in. (50 mm) abrasion test disks.

2. The two 150-gm. samples were titrated to determine the amount of cement in the mortar. The 1000-gm. sample was oven dried to determine the water content. (While it is recognized that this type of test will not determine "free mixing water" to calculate the true water-cement ratio, it does provide a relative measure of wetness.)

3. The set of three mortar cubes were field cured for one day, then stripped from the mold and water cured for the remainder of 7 days at which time they were tested for compressive strength.

Knowing the "relative" amount of moisture and cement in the mortar samples along with the compressive strengths, a comparison of the W/C ratio vs. strength was made.

4. The two abrasion disks were tested to determine the comparative resistance to abrasion.

The results of these test are shown in Table 4.

Summary

Initial skid resistance was satisfactory on all test sections at West Covina (see Table 5). It is too early to determine which of the different surface types containing broadcast aggregate might perform better. Future periodic testing will consist of (1) skid resistance measurements, (2) photographs, and (3) texture measurements.

LONG BEACH

The second project was located on Route 91 near the City of Long Beach, also in Los Angeles County. The main purpose of this test was to evaluate the effectiveness of imparting transverse grooves into the surface of fresh concrete with a steel grooving plate.

The grooving plate or head was fabricated from a 22 x 24 x 1/2-in. (560 x 610 x 13 mm) steel plate which was machined to produce ribs 1/10-in. (2.5 mm) wide by 3/16-in. (5 mm) high, spaced

TABLE 4

TESTS ON CONCRETE - WEST COVINA

Sample Series Number (see Text)	Compressive Strength PSI	W/C Ratio	Abrasion Loss - Gms (in 3 Minutes)
1A	4750	.49	11
1B	2860	.65	14
1C	2340	.68	14
2A	6440	.47	12
2B	3790	.61	12
2C	2190	.72	19
3A	7180	.40	9
3B	4390	.51	11
3C	3540	.59	12
4A	6170	.51	9
5A	6240	.49	9
6A	5590	.48	9
7A	6090	.50	11

TABLE 5

SKID RESISTANCE MEASUREMENTS - WEST COVINA
(Test Method No. Calif. 342)

Initial Tests*

	Skid No.
Control Sections	0.37
No Water Added by Paver	0.33
Slag Aggregate Texture	0.39
Crushed Aggregate Texture	0.36
Lightweight Aggregate Texture	0.34

Note: Each value is an average of 3 tests. A minimum value of 0.30 is required.

*More recent test results had to be discarded because of equipment malfunction which was undetected during testing.

at 3/4-in. (19 mm) centers. The head was mounted on a transverse tape inserting machine and equipped with an external vibrator (see Figure 14).

Grooving of the roadway surface was attempted at different time intervals following the paving operation. The first trial was made while the surface was quite wet (Figure 15), and with the external vibrator turned off. It was found that the formed grooves tended to fill up with mortar following the pass of the grooving head. A second trial was made in the same time period but with the vibrator turned on. The result was even more filling of the grooves.

Approximately one hour after paving, another trial was made with and without the vibrator on, and with the speed of transverse travel varied. The grooves were improved with the vibrator on and a fairly fast rate of travel, but there was still a slight tendency for the grooves to fill in following the passing of the head.

A third trial took place 1-1/2 hours following pavement placing. The top surface appeared to be of the proper consistency, but the concrete below the surface appeared to have become sufficiently set to inhibit the desired penetration. As a result, the grooving head was riding up and over some of the larger aggregate particles. To correct this, the grooving head was adjusted to allow the leading edge to be slightly higher than the trailing edge. This adjustment resulted in a more satisfactory texture (see Figures 16 and 17).

Summary

From these limited tests, it appeared that, with certain precautions, a satisfactory texture could be obtained with

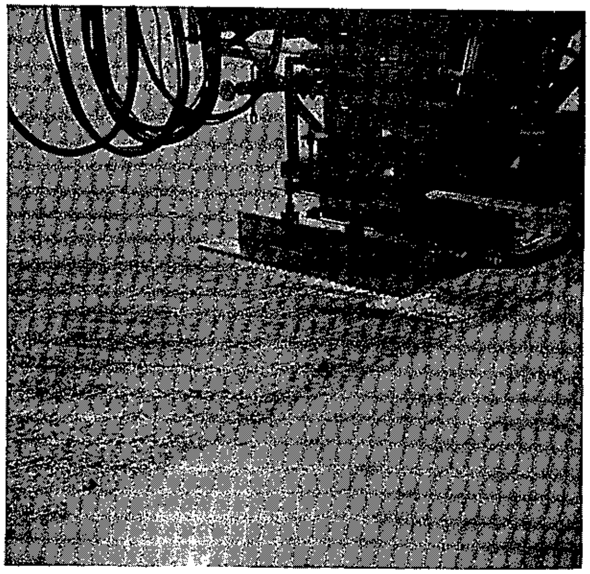


Figure 14 - Transverse grooving head mounted on machine with vibrator attached to top of head.

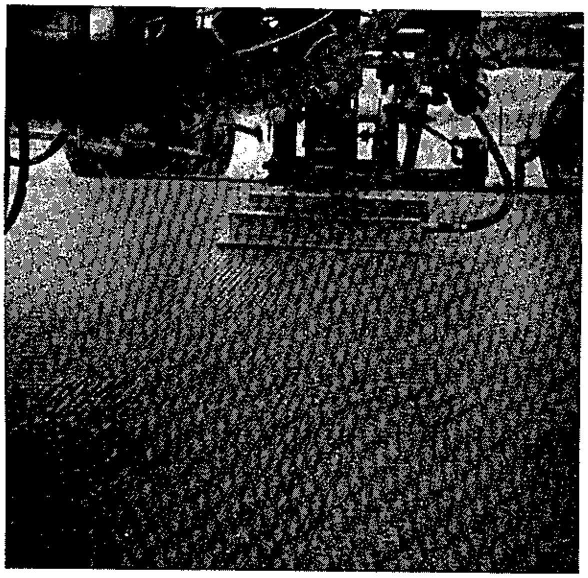


Figure 15 - First pass with grooving head. Note wet appearance of surface.

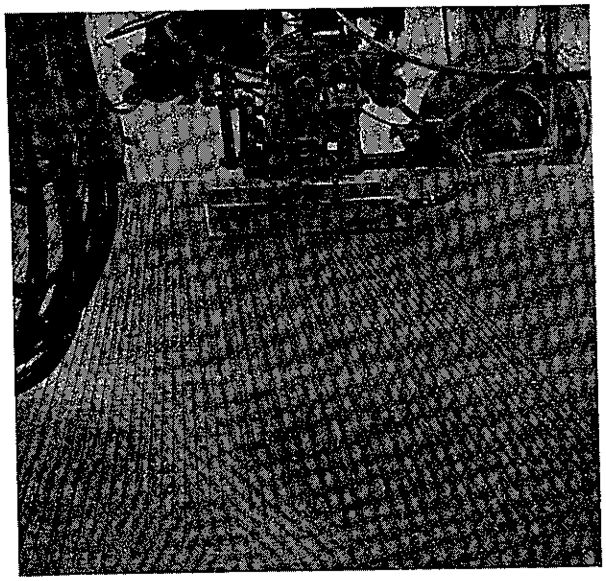


Figure 16

Final pass with grooving head.

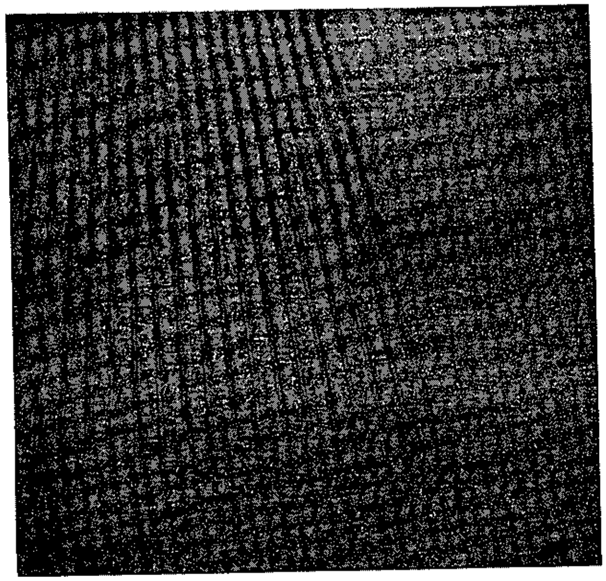


Figure 17

Closeup or final grooved texture.

the grooving plate. Best results were obtained using the following procedure:

1. Vibrator on.
2. Fairly fast rate of travel.
3. Leading edge of plate higher than trailing edge.
4. Surface moisture at a minimum.

Periodic monitoring will continue to determine the effectiveness of the experimental texturing. Tests will include (1) skid resistance measurements; (2) photographs; and (3) texture measurements.

SAN DIEGO

A third experimental site was located on Interstate 805 in the City of San Ysidro in San Diego County. The purpose of the tests was to investigate transverse texturing of fresh concrete.

The following devices were mounted on an EDOCO transverse joint inserting machine:

1. Nylon bristle broom, 5 ft. (1.5 m) long, 6 in. (150 mm) long bristle, 0.035 in. (1 mm) diameter; 2 rows of bristles on 3/4 in. (19 mm) centers.

2. Spring steel wire comb, 5 ft. (1.5 m) long, single row of 0.032 in. (1 mm) x 0.083 in. (2 mm) flat steel wire 1/4 in. (6 mm) centers, 3 in. (75 mm) exposed.

3. Spring steel wire comb, 5 ft. (1.5 m) long, single row of 0.025 in. (0.6 mm) x 0.126 in (3 mm) flat steel wire, 1/2 in. (13 mm) centers, 5 in. (127 mm) exposed.

4. Grooving plate, 17 x 36 x 1/2 in. (430 x 915 x 13 mm) steel plate with a 5 x 36 x 1/2 in (127 x 915 x 13 mm) trailing plate - ribs 1/10 in. (2.5 mm) wide by 3/16 (5 mm) deep spaced at 3/4 in (19 mm) centers.

A total of nine test sections were established to evaluate the use of the above devices. Table 6 shows the location and length of each test section. Included in these sections were two locations where "Astroturf" was dragged longitudinally and three other locations where the standard longitudinal broom was used as the control texture. See Figures 18 through 22 showing the various texturing devices used.

The first texturing device used was the grooving plate. Except for a few changes this device was the same as that used at Long Beach.

Changes included:

1. Widening the plate from 24 in. (610 mm) to 36 in. (915 mm).
2. Separating the single plate into two parts connected by a neoprene sheet.
3. A vibrator was mounted on the larger leading plate (see Figure 18).

The first attempts at texturing with the plate gave unsatisfactory results. There were problems keeping the plate parallel to the concrete surface and since the machine wheels rested on the subgrade which was not necessarily in the same plane as the pavement, it was impossible to apply a constant pressure to the concrete surface. Movement of the plate tended to push up aggregate near the surface. In an effort to reduce pushing aggregate, the trailing plate was removed and the concrete was allowed to set for a longer period. Further attempts at

TABLE 6

LOCATION OF TEST SECTIONS
RTE. I-805 - SAN DIEGO AREA

Station	Length Ft.	Texture Type
132+25 - 144+50	1224	Longit. broom (Standard)
144+50 - 149+50	500	Transv.grooves, 1/2 in. centers, 5 in. tines
149+50 - 154+50	500	Longit. "Astroturf"
154+50 - 156+25	175	Transv.grooves, 1/2 in. centers, 5 in. tines
156+25 - 159+50	325	Longit. "Astroturf"
159+50 - 164+50	500	Transv.grooves, 1/2 in. centers, 5 in. tines
164+50 - 169+00	450	Longit. broom (Standard)
169+00 - 169+50	50	Transv.grooves, 1/4 in. centers, 3 in. tines
169+50 - 170+00	50	Transv.grooves, 3/4 in. centers, 3 in. tines
170+00 - 177+50	750	Longit. broom (Standard)
177+50 - 182+00	450	Transv.grooves, 3/4 in. centers, 3 in. tines
182+00 - 182+20	20	Transv.grooves, 1/2 in. centers, 4 in. tines (5 in. tines bent to 4 in.)
182+20 - 185+50	330	Longit. broom (Standard)
185+50 - 188+00	250	Transv.grooves, 1/2 in. centers, 4 in. tines (5 in. tines bent to 4 in.)
188+00 - 198+50	1000	Transv. Texture using nylon bristle broom

Note: 1 ft. = .3048 m
1 in. = 25.4 mm

Figure 18 - Transverse Grooving Plate (Modified).

Figure 19 - Longitudinal texturing with "Astroturf".

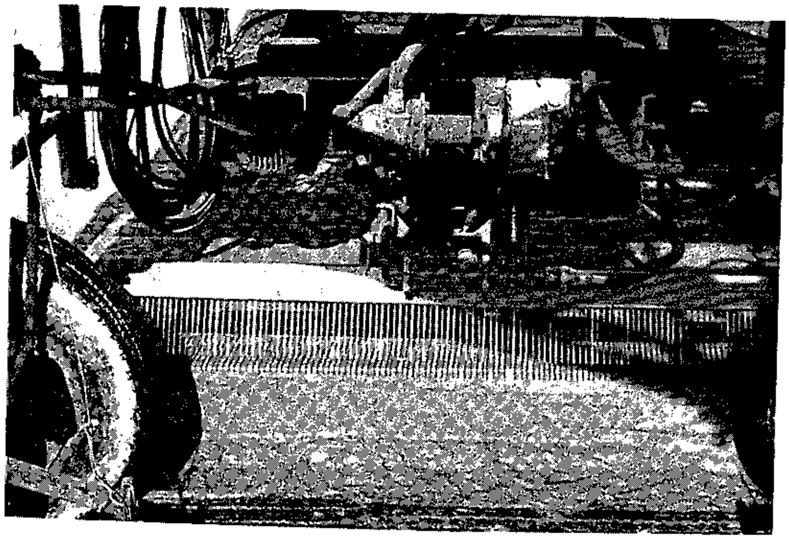


Figure 20 - Transverse Steel Tine Comb 5 in. (127 mm) tines at 1/2 in. (13 mm) centers.

Figure 21 - Transverse Steel Tine Comb 5 in. (127 mm) tines bent to make 4 in. (100 mm) tines at 1/2 in. (13 mm) centers.

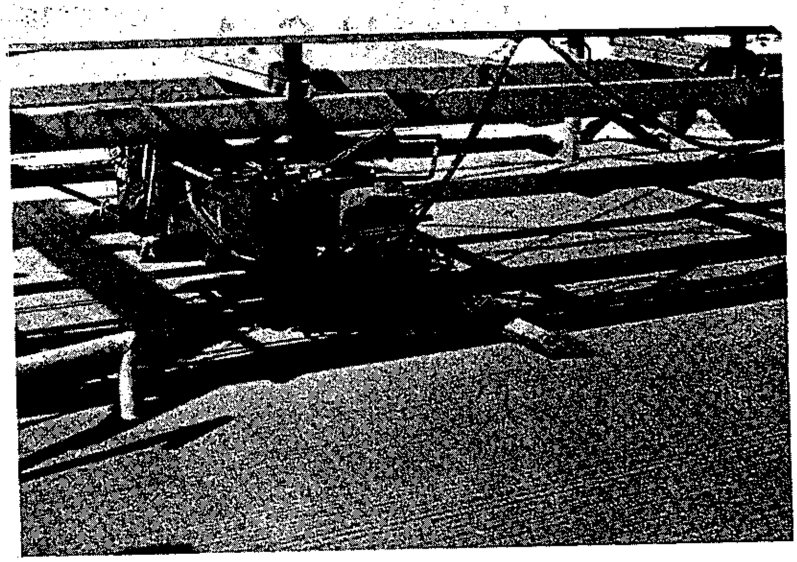


Figure 22 - Transverse texturing with a nylon broom with two rows of 6 in. (150 mm) long bristles spaced at 3/4 in. (19 mm) centers.

texturing with this device gave similar results. The size of the plate (only three feet (0.9 m wide) and rate at which it moved made it impossible for the machine to keep up with the paving train and it was decided to try another texture type. The small area textured with the plate was bull floated and retextured longitudinally with a broom.

The wire tine comb with 5 in. (127 mm) tines spaced at 1/2 in. (13 mm) c-c and tines 0.025 in (0.6 mm) x 0.126 in (3 mm) was tried next on a 500 ft. (152 m) section. Texture obtained with this device had good groove width, but the depth was too shallow. The angle the tines made with the concrete surface and the pressure on the head were varied on two other areas to try and obtain a deeper texture. The general feeling of those present was that the tine thickness of 0.025 in (0.6 mm) was not substantial enough to impart the desired groove depth, especially if texturing was attempted a little late.

The speed of the texturing machine was slow when compared to the speed of the paving train, causing the texturing operation to be unduly delayed. Two sections were then textured longitudinally with "Astroturf" (see Figure 19) between those areas textured with the 5 in. (127 mm) tines. This texture could be applied much faster and presented an opportunity to "catch up" to the paving train. The texture produced by the "Astroturf" was similar in appearance to that produced by the longitudinal broom. This similarity is further verified when Sand Patch tests and skid numbers are compared (see Table 7). Also, see profiles in Appendix A.

Next tested was the wire tine comb with 3 in. (75 mm) tines spaced @1/4 in. (6 mm) c-c and tines 0.032 in. x 0.083 in (0.8 mm x 2 mm). The texture produced with this device was too severe and the tines had a tendency to undercut to the

TABLE 7

SAND PATCH TESTS AND
SKID RESISTANCE MEASUREMENTS
(Test Method No. Calif. 342)

Test No.	Before Traffic		After 9 Months of Traffic		Remarks
	Friction Coefficient	Sand Patch Avg. Depth Inches	Friction Coefficient	Sand Patch Ave. Depth Inches	
1	.37	0.031	.41	0.027	Control (Longit. Broom)
2	.37	0.028	.37	0.024	Control (Longit. Broom)
3	.36	0.036	.38	0.040	1/2 in. x 5 in. Wire Tine (Transv.)
4	.37	0.031	.36	0.019	"Astroturf" (Longit.)
5	.41	0.063	.39	0.055	1/4 in. x 3 in. Wire Tine (Transv.)
6	.42	0.057	.38	0.039	3/4 in. x 3 in. Wire Tine (Transv.)
7	.42	0.051	.37	0.047	1/2 in. x 4 in. Wire Tine (Transv.)
8	.44	0.026	.37	0.022	Nylon Broom (Transv.)
9	.38	0.038	.41	0.023	Control (Longit. Broom)

Note: 1 in. = 25.4 mm

adjoining groove. In an effort to reduce this undercutting, every two out of three tines were bent up out of the way. This, in effect, gave a comb with 3 in. (75 mm) tines spaced at 3/4 in (19 mm) center to center.

The resulting texture had good groove depth but the individual grooves were not of sufficient width. Comparison of groove depth between the 3/4 in x 3 in. (19 mm x 75 mm) tines and the 1/2 in. x 5 in. (13 mm x 127 mm) tines can be seen in the profiles in Appendix A.

One more attempt was made with the 1/2 in (13 mm) spaced wire tine comb to try and get a deeper groove. The 5 in. (127 mm) tines were bent into an "L" shape (see Figure 21) giving an effective length of 4 in. (100 mm). As can be seen on the profiles a deeper groove was obtained, but due to the tine configuration a pulling of grout was observed.

The nylon bristle broom with 6 in (150 mm) bristles was used on the remaining portions of pavement within the test area. The broom was mounted on the transverse joint inserting machine and also used to texture transversely. The texture produced with this device was similar in appearance to the "Control" texture (see Figure 22).

Test Results

Comparative noise studies were performed, in addition to skid tests, sand patch tests and texture profiles, on each individual section.

The nine sections were skid tested before, and about 9 months after being opened to traffic. Comparisons of skid number and sand patch tests are shown in Table 7.

Comparative sound level studies were conducted on the experimental sections. Noise level generation at the six locations were compared to the longitudinal broomed sections. Measuring equipment was located 5 ft (1.5 m) above the ground surface in the median 50 ft. (15 m) from the centerline of the lane being tested (runs made in lane #4). Figure 23 shows the equipment setup.

Two manual readings were made on two separate sound level meters; one meter was connected to a graphic level recorder. All sound level meters were set in the fast response with the A weighting network. The sound level meters and graphic level recorder were calibrated before each run. Three test vehicles were used in the test; test vehicles made a minimum of three "coast bys" at 50 mph (80 km/hr) and 35 mph (56 km/hr) each. Runs were made in both directions yielding no difference in readings. A description of the three vehicles used is as follows:

No. 1 1974 Pinto Stationwagon with Sears radial tires, CR-78-13, Load Range B.

No. 2 1970 Dodge Coronet with B.F. Goodrich Silvertown Belted, G-78-14, Standard 6-rib Bias Ply Tire.

No. 3 1972 Dodge Power Wagon pickup, B.F. Goodrich Nylon Extra Traction, 7.50X16 LT, 8 Ply Rating.

Seven test areas were established; one was a control section and the others were of each different type of texture.

Table 8 gives the average decibels (dB) at each speed and also the decibels above or below the control.

Standard tread design shows significant increases in noise level when comparing the 5 transverse textures to the control texture.

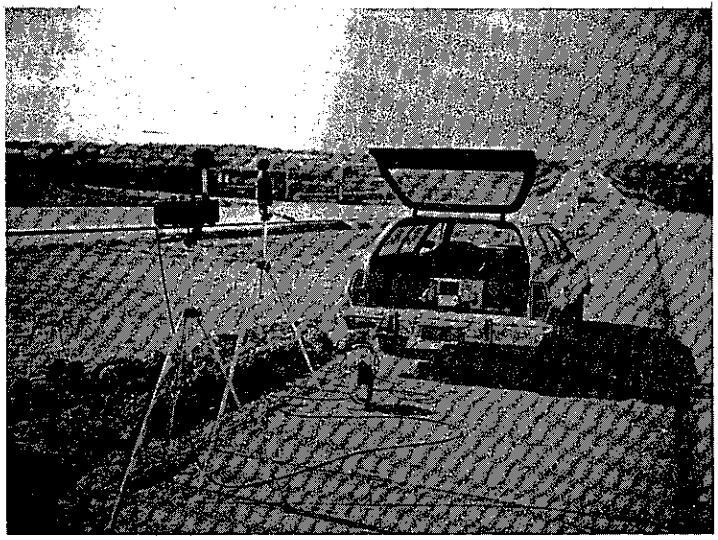


Figure 23 - Sound equipment setup San Diego.

TABLE 8

AVERAGE dBA AT 35 MPH AND 50 MPH, RTE. I-805

Station	Texture Description	Average dBA @ 35 mph			Average dBA @ 50 mph		
		Pinto	Coronet	Power Wagon	Pinto	Coronet	Power Wagon
143+00	Control - Standard Longit. Broom	57.5 -	62.2 -	71.9 -	64.3 -	68.0 -	79.1 -
147+00	Transverse Wire Tine(1/2 in.x5 in.)	60.8 +3.3	66.6 +4.4	71.3 -0.6	67.5 +3.2	71.6 +3.6	79.1 0.0
152+00	"Astroturf" (Longitudinally)	58.1 +0.6	62.1 -0.1	71.0 -0.9	64.2 -0.1	67.9 -0.1	80.1 +1.0
169+00	Transverse Wire Tine(1/4 in.x3 in.)	63.3 +5.8	67.5 +5.3	73.3 +1.4	69.0 +4.7	74.4 +6.4	80.2 +1.1
181+00	Transverse Wire Tine(3/4 in.x3 in.)	60.8 +3.3	64.5 +2.3	72.1 +0.2	67.8 +3.5	71.0 +3.0	81.1 +2.0
186+00	Transverse Wire Tine(1/2 in.x4 in.)	62.3 +4.8	65.8 +3.6	71.6 -0.3	67.4 +3.1	72.8 +4.8	79.3 +0.2
197+00	Transverse Nylon Broom	62.0 +4.5	65.3 +3.1	71.6 -0.3	68.1 +3.8	71.2 +3.2	79.5 +0.4

NOte: 35 MPH = 56 km/hr
50 MPH = 80 km/hr
1 inch = 24.5 mm

Radial tires show an increase in noise generated of 3.3 to 5.8 dB at 35 mph (56 km/hr) and 3.1 to 4.7 dB at 50 mph (80 km/hr). Standard Bias-Ply tires show an increase in noise generated of 2.3 to 5.3 dB at 35 mph (56 km/hr) and 3.0 to 6.4 dB at 50 mph (80 km/hr).

Though the noise level generated by the test vehicle with the extra traction tires was higher than the other two, mud and snow tires showed the least significant <u>increase</u> in noise level. At 35 mph (56 km/hr) the greatest increase was 1.4 dB on the 1/4 in. x 3 in. (6 x 75 mm) wire tine texture and 2.0 dB on the 3/4 in. x 3 in. (19 x 75 mm) wire tine texture at 50 mph (80 km/hr).

The least increase in noise generated by the standard tread was observed on the 3/4 in. x 3 in. (19 x 75 mm) wire tine texture. This increase was 2.3 dB at 35 mph (56 km/hr) and 3.0 dB at 50 mph (80 km/hr). Noise level generated by the "Astroturf" most closely resembled that generated by the control longitudinal broom.

It should be noted also that the least noise generated by the pick-up vehicle exceeded that generated by either of the other two regardless of the texture being tested.

Summary

Additional trials with the grooving plate proved to be unsatisfactory. The transverse wire tine texturing with 3/4 in. (19 mm) spacing generated about 2 to 3 dBA more noise than longitudinal broom type textures. Further testing of these areas will continue on a periodic basis.

GEYSERVILLE

A fourth experiment was conducted on Hwy. 101 in the City of Geyserville in Sonoma County. On this particular project the contractor requested and received permission to use a wire tine device dragged longitudinally as the standard method of texture. The comb was constructed of double stainless steel tines approximately 4 in. (100 mm) long set back to back and were spaced 1/2 in. (13 mm) c-c. Two tines together provided added stiffness (see Figure 24). The texturing device was mounted on a framework on the back of the pipe float finisher (see Figure 25) and could be raised or lowered by two hydraulic rams.

A wire tine comb was developed at the laboratory as a direct result of the transverse texturing done in San Diego. This device had 4 in. (100 mm) spring steel tines spaced at 3/4 in. (19 mm) center to center. The tines were mounted in a wooden frame 24 ft. (7.3 m) wide. With some modifications the 3/4 in. (19 mm) spaced comb was mounted to the pipe float finisher at Geyserville and about 4600 feet (1.4 km) of pavement was textured with this device (see Figure 26). The remainder of the job was textured with the contractors comb.

Test Results

Prior to completion of the project, pavement textured with the 1/2 in. (13 mm) spaced tines was tested for possible adverse affects on motorcycles. Longitudinal grooves have a tendency to cause "tracking" for some vehicles. The pavement was tested by representatives of the Transportation Laboratory and California Highway Patrol. Three different sized motorcycles were used in the test. Each motorcycle was driven at slow and highway speeds by several different riders. The concensus was that there were no hazardous effects from the grooving.

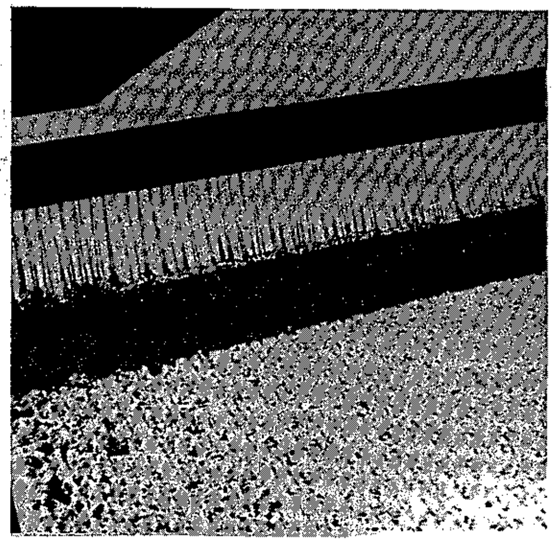


Figure 24 - Contractor's double steel tine comb, 4 in. (101.6 mm) tines spaced at 1/2 in. (12.7 mm) centers.

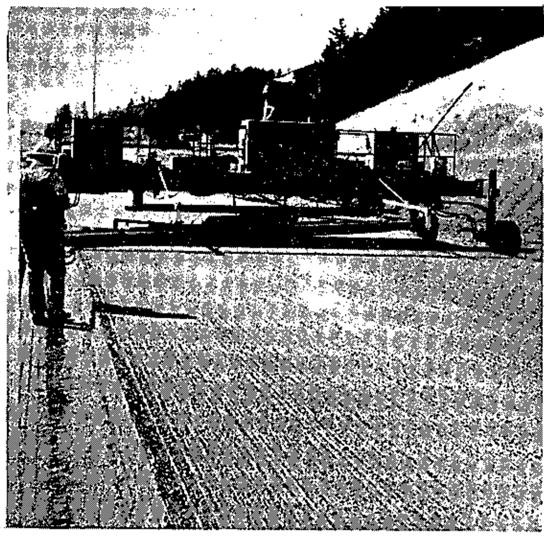


Figure 25 - CMI Pipe Float Finsher with texture attachment.

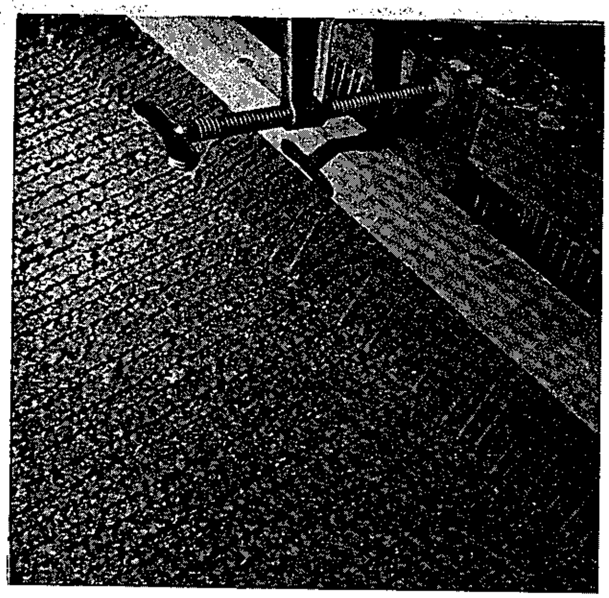


Figure 26 - Laboratory fabricated wire tine comb, 4 in. (101.6 mm) tines spaced at 3/4 in. (19.05 mm) centers.

Skid and sand patch tests, along with texture profiles were taken at four sites grooved with the 1/2 in. (13 mm) spaced tines and four sites grooved with the 3/4 in. (19 mm) spaced tines. Individual sections were selected because of their apparent varying texture depth. Location of the test sections, together with skid number and sand patch before and after traffic appear in Table 9.

DISCUSSION AND SUMMARY

The concrete paving industry has experienced numerous developments since the beginning of the twentieth century. Most advancements have been closely related to production items such as mixing, hauling, placing and finishing. While the quality of the surface texture and the skid resistance have been of concern, the methods of achieving it have been primarily through construction operations involving a burlap drag or texturing broom. Neither approach has served to provide a texture of much permanence although initially they are quite satisfactory.

Burlap or broom texturing followed by the application of steel tines for the purpose of imparting a groove with appreciable depth offers a texture of improved durability. After the micro-texture is worn away the grooves remain to provide escape routes for water between a tire and the pavement surface. The benefits of grooving existing pavements by diamond saws are well established.

The question of whether pavement grooves should be oriented longitudinally or transversely has been controversial, whether for new construction or on older pavements. There are advantages and disadvantages for each and a clear superiority for either has not been established.

TABLE 9

SAND PATCH TESTS AND
SKID RESISTANCE MEASUREMENTS
(Test Method No. Calif. 342)

	Before Traffic				After 3 Months of Traffic			
Location	Friction Coefficient	Avg. F.C.	Sand(1) Patch	Avg.(2) S.P.	Friction Coefficient	Avg. F.C.	Sand(1) Patch	Avg.(2) S.P.
1	.45		0.105		.40		0.068	
2	.43	.44	0.079	0.087	.35	.37	0.043	0.051
3	.44		0.094		.36		0.051	
4 (1/2 inch)	.42		0.070		.37		0.043	
5	.50		0.051		.37		0.034	
6	.45	.48	0.035	0.038	.36	.37	0.034	0.022
7	.47		0.031		.37		0.019	
8 (3/4 inch)	.48		0.033		.37		0.014	

(1) Depth in inches; each number an average of 3 tests.

(2) Depth in inches; average depth of all 4 locations.

1 inch = 25.4 mm

Transverse tine texturing offers the advantage of improved stopping ability and rapid removal of rain water from the pavement surface. A greater tire noise is generated and there is among some highway engineers the belief that wear rates are higher. Construction is somewhat more complicated by equipment requirements and by coordinating the tining with paving progress on hot dry days.

Longitudinal tine texturing imparts a "tracking" effect to the pavement surface by providing resistance to lateral movement. The ability of longitudinal diamond grooving to reduce accidents is well established. There is no reason to believe that the grooves result ing from steel tines on new construction will not be equally successful as long as some groove depth remains. It lends itself more readily to pavement construction under a variety of conditions. An "uneasy" ride condition is imparted to light motorcycles with certain tire treads, and light passenger cars sometime experience a slight lateral drift. These problems are considered to be relatively minor.

As a result of the findings of the research described herein and general experience with longitudinal texturing, California now specifies longitudinal tine texturing on new concrete pavement construction. The spacing of the grooves is 3/4 inch (19 mm) center to center, the width of the groove is 3/32 inch (2.38 mm) to 1/8 inch (3.18 mm), and the depth a nominal 3/16 inch (4.76 mm). It is believed that this type of groove construction will provide a desirable, safe pavement texture with significantly improved durability.

REFERENCES

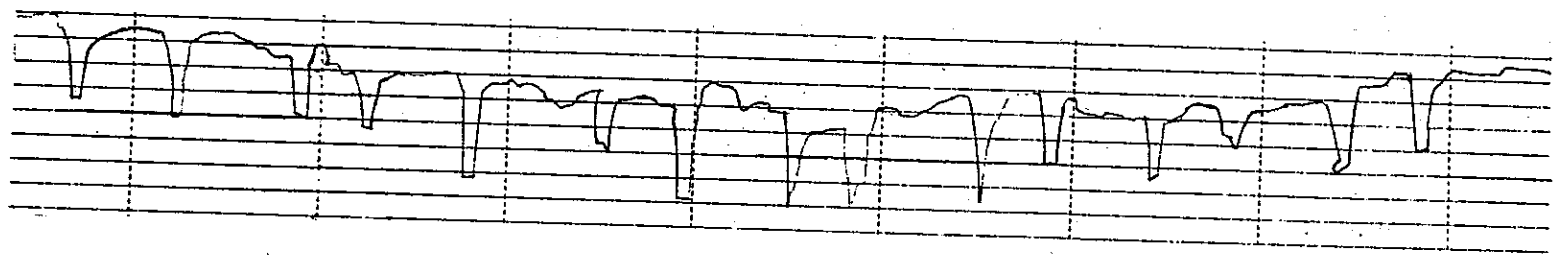
1. Portland Cement Concrete Pavement Texture Quality Investigation; California Department of Transportation, January 1975.

2. Determination of Desirable Finish for Concrete Pavement; Department of Transportation of Georgia, July 1974.

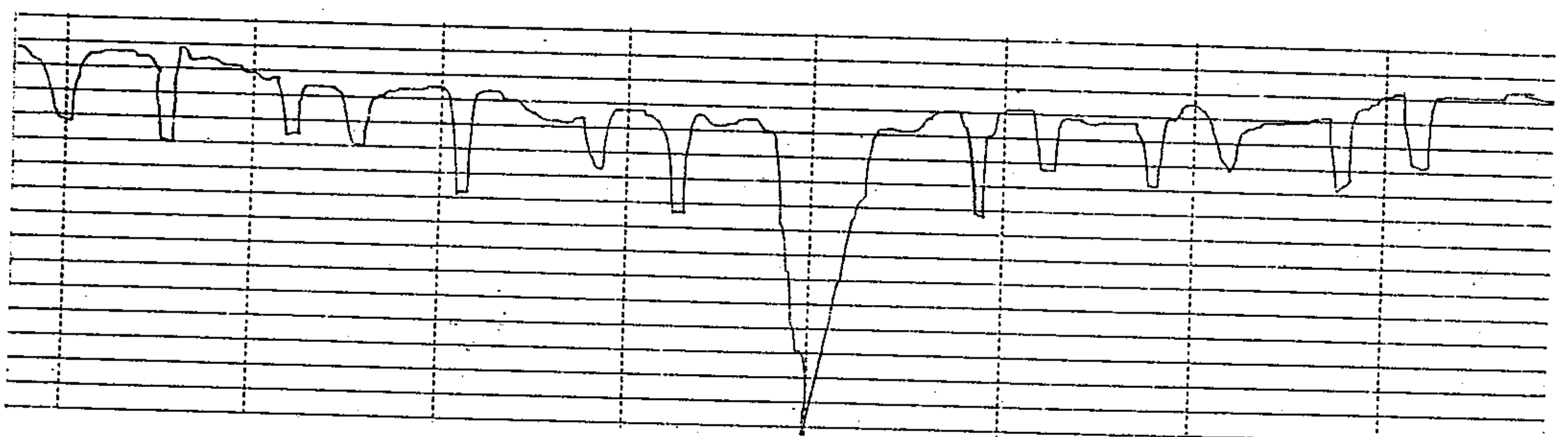
3. Evaluation of Full-Scale Experimental Concrete Highway Finishes; Texas Transportation Institute, September 1974.

APPENDIX A

ENGR'S. STA. 147+00 - TRANSVERSE GROOVES, 5 IN. (127mm) AT 1/2" IN. (12.7mm) CENTERS



Before Traffic

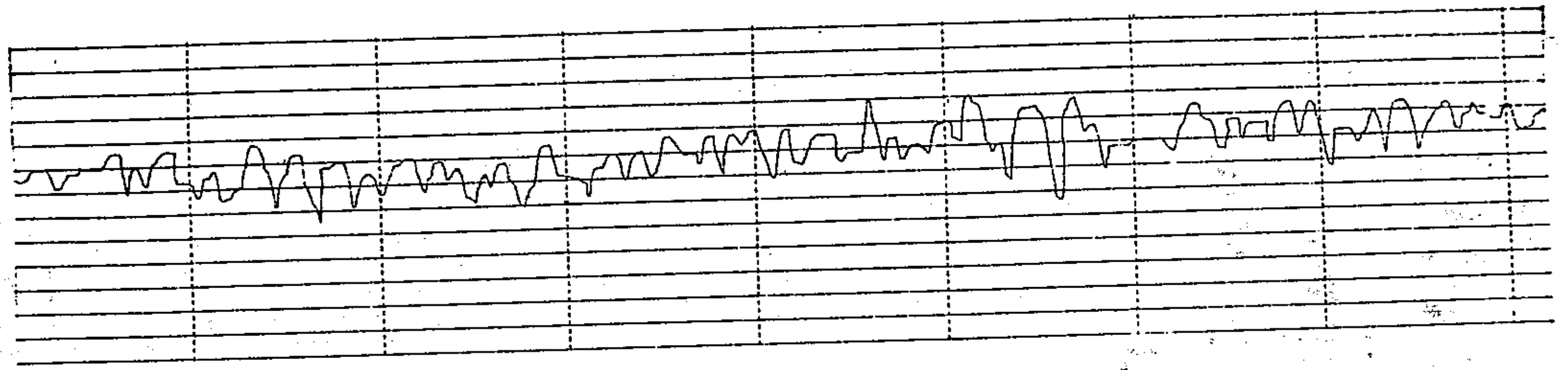


After Traffic

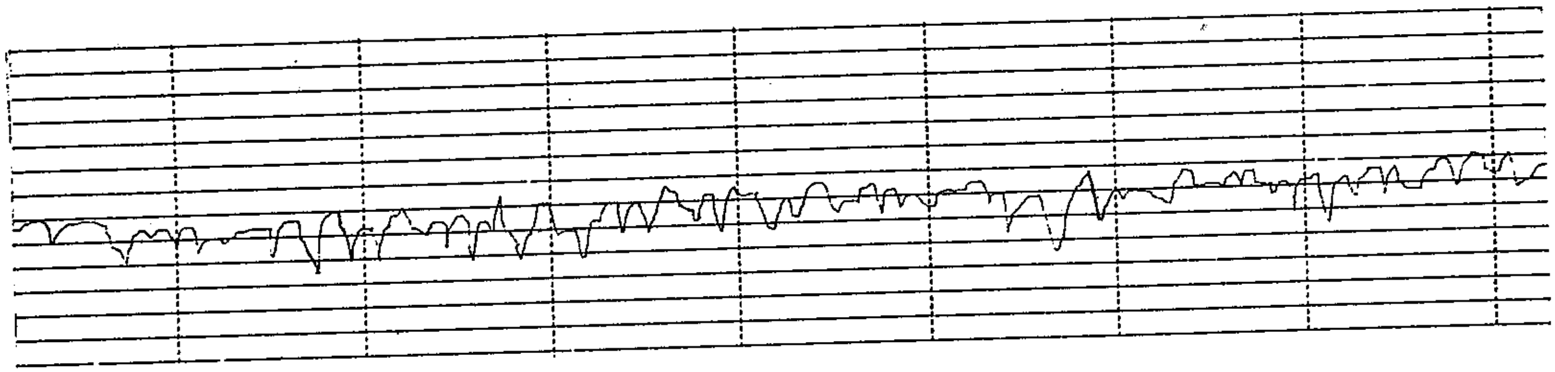
Scale: H = 1:1
V = 5:1

Figure A-1

ENGR'S. STA. 151+00 - LONGITUDINAL TEXTURE USING "ASTROTURF"



Before Traffic

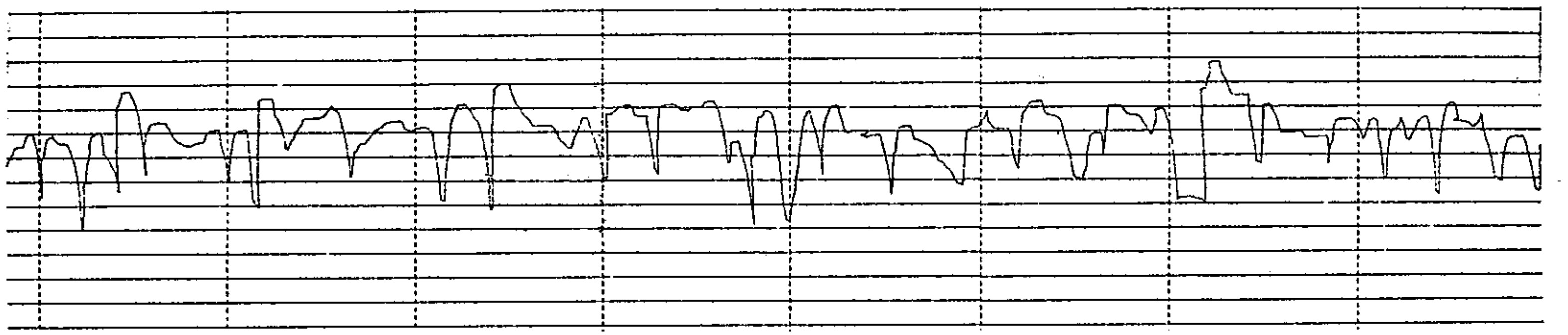


After Traffic

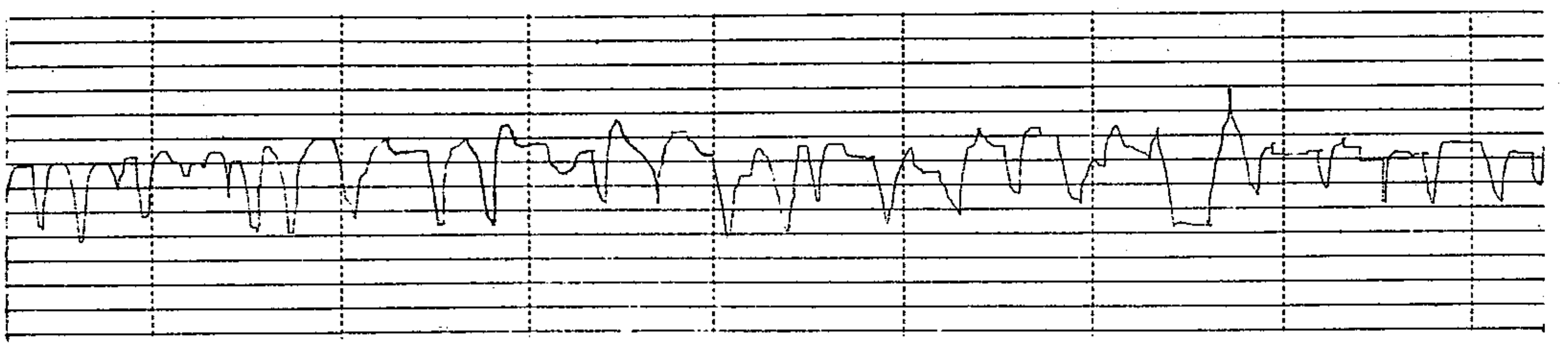
Scale: H = 1:1
V. = 5:1

Figure A-2

ENGR'S. STA. 169+25-TRANSVERSE GROOVES, 3 IN. (76.2 mm) TINES AT 1/4 IN. (6.35 mm) CENTERS



Before Traffic

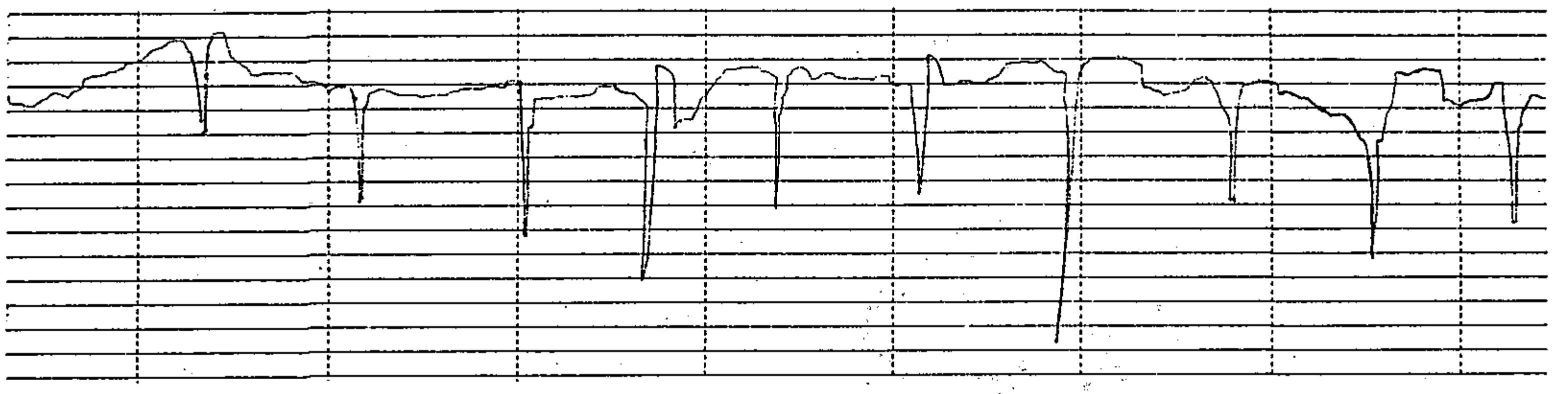


After Traffic

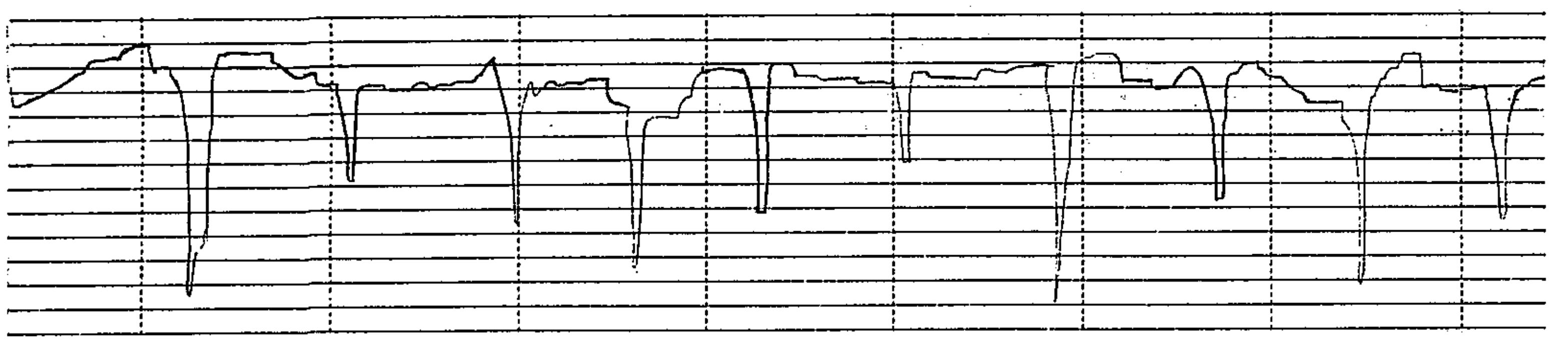
Scale: H = 1:1
V = 5:1

Figure A-3

ENGR'S. STA. 180+00 - TRANSVERSE GROOVES, 3 IN. (76.2 mm) TINES AT 3/4 IN (19.05 mm) CENTERS



Before Traffic



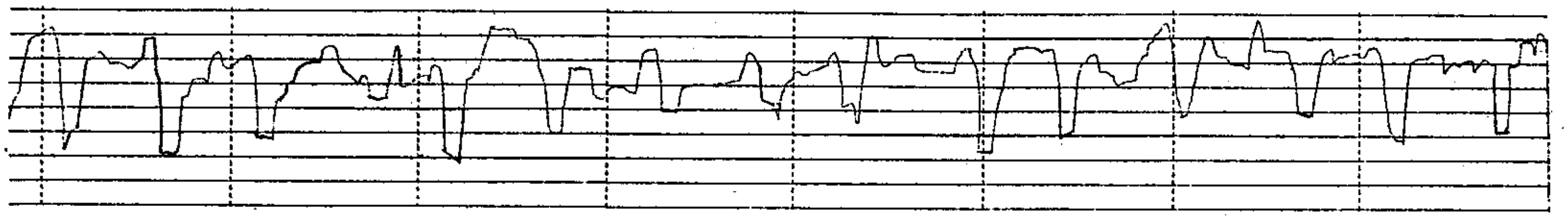
After Traffic

Scale: H = 1:1
V = 5:1

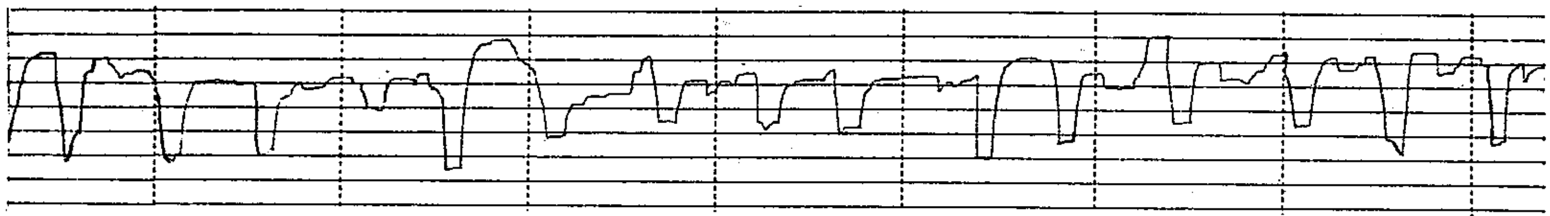
Figure A-4

ENGR'S. STA. 182+00- TRANSVERSE GROOVES,

4 IN. (101.6mm)(L-SHAPED) TINES AT 1/2 IN. (12.7mm) CENTERS



Before Traffic

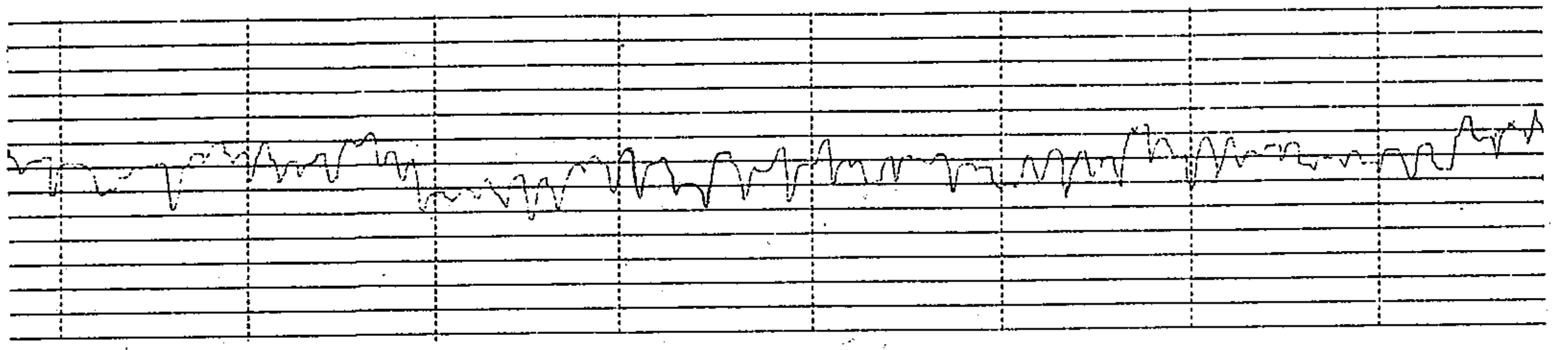


After Traffic

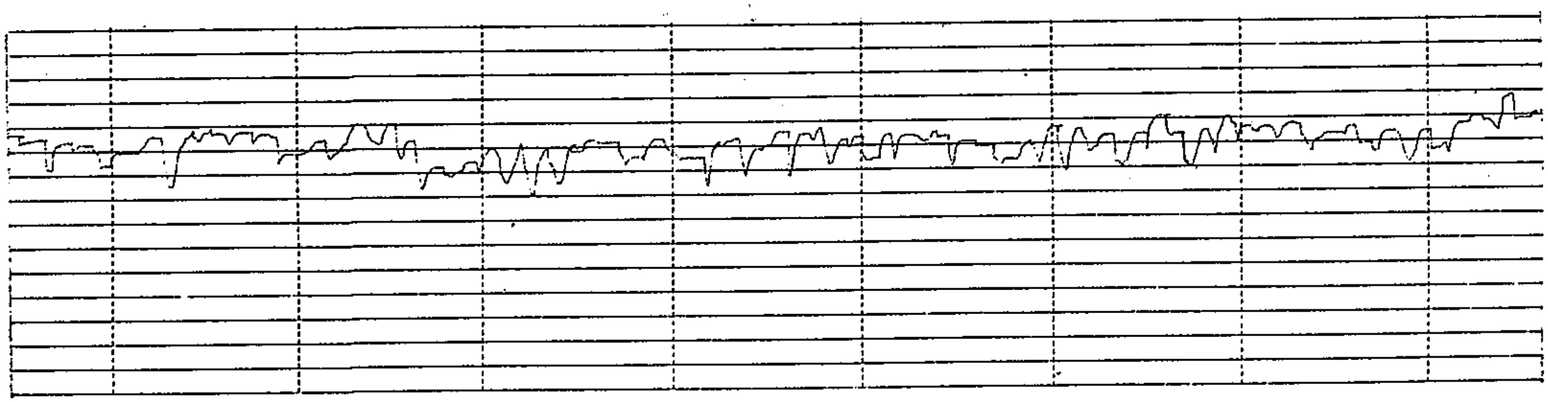
Scale: H = 1:1
V = 5:1

Figure A-5

ENGR'S. STA. 198+00 - TRANSVERSE TEXTURE NYLON BRISTLE BROOM



Before Traffic

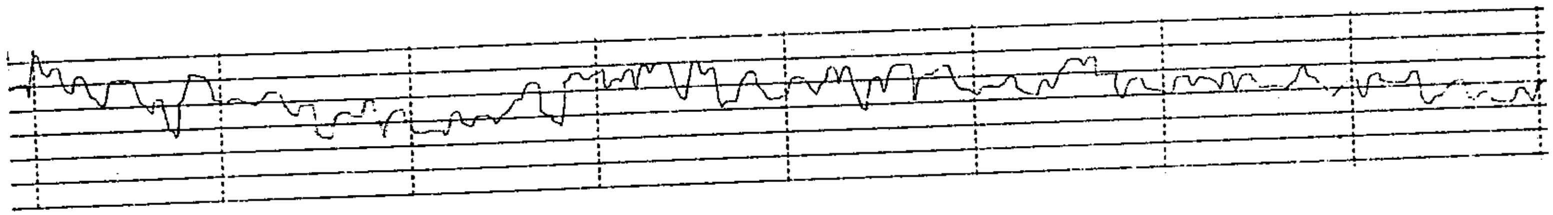


After Traffic

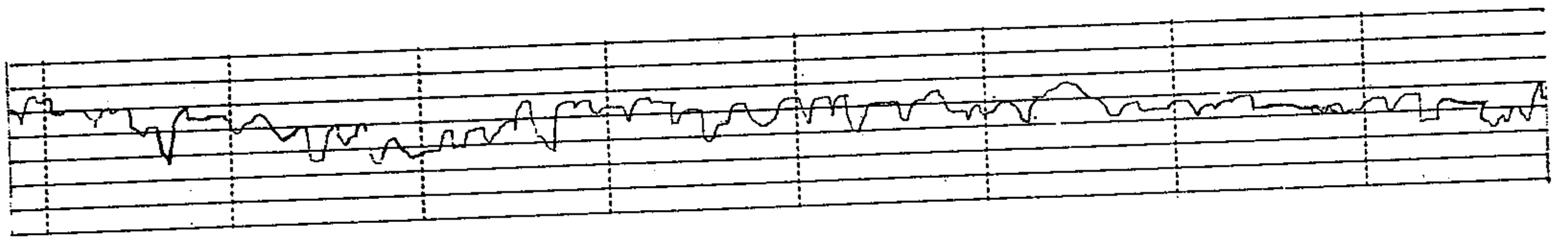
Scale: H = 1:1
V = 5:1

Figure A-6

ENGR'S. STA. 209+00 – CONTROL, LONGITUDINAL BROOM



Before Traffic



After Traffic

Scale: H = 1:1
V = 5:1

Figure A-7

APPENDIX B

Standard Specification For Texturing PCC Pavements

40-1.10 Final Finishing.--In advance of curing operations, pavement shall be given an initial and final texturing. Initial texturing shall be performed with a burlap drag or broom device which will produce striations parallel with centerline. Final texturing shall be performed with a spring steel tine device which will produce grooves parallel with centerline.

Burlap drags, brooms and tine devices shall be installed on self-propelled equipment having external alignment control. The installation shall be such that when texturing, the area of burlap in contact with the pavement surface shall be maintained constant at all times. Broom and tine devices shall be provided with positive elevation control so that down pressure on pavement surface is maintained constant at all times during texturing to achieve uniform texturing without measurable variations in pavement profile. Self-propelled texturing machines shall be operated so that travel speed when texturing is maintained constant. Failure of equipment to conform to all provisions in this paragraph shall constitute cause for stopping placement of concrete until the equipment deficiency of malfunction is corrected.

Spring steel tines of the final texturing device shall be rectangular in cross-section, 3/32 to 1/8 inch (2.38 to 3.18 mm) wide, on 3/4 (19 mm) centers, and of sufficient lengths, thickness and resilience to result in grooves approximately 3/16 inch (5 mm) deep in the fresh concrete surface. Final texture shall be uniform in appearance with substantially all of the grooves having depths of 3/16 inch ± 1/8 inch (5 mm ± 3.2 mm).

Initial and final texturing shall produce a surface having a coefficient of friction not less than 0.30 as determined by Test Method No. Calif. 342.

Tests to determine coefficient of friction will be made before pavement is opened to public traffic, but not sooner than 7 days after concrete placement. Pavement containing areas that have a coefficient of friction less than 0.30 shall be grooved as directed by the Engineer before opening it to public traffic.