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TEXTURING BRIDGE DECKS
A FINAL REPORT

APRIL, 1986

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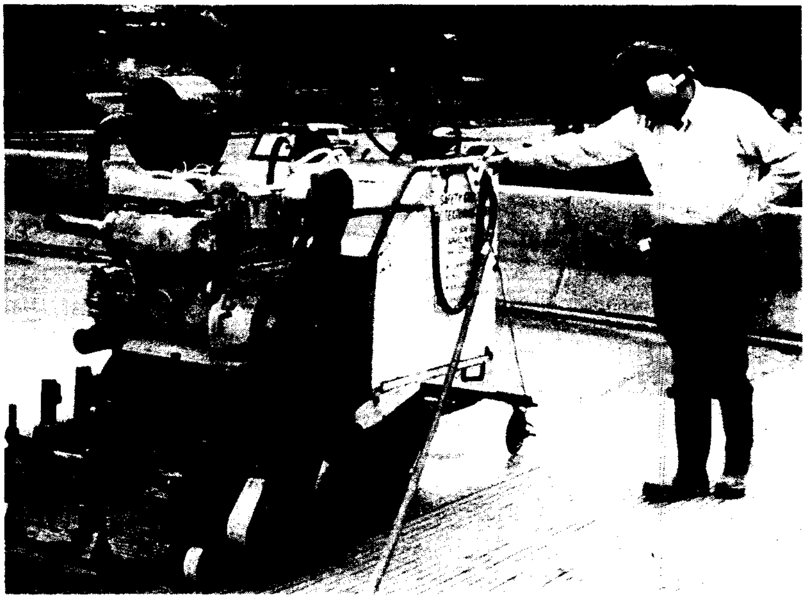

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16. Abstract

This report documents a special study undertaken to evaluate the effectiveness of NJDOT's current specification for bridge deck tining. Several tining operations were observed and the resultant finish judged to be inadequate, even though methods outlined in the specification were followed. A number of bridge decks were measured, utilizing tire tread depth gauges and a random sampling plan. This follow-up testing confirmed that, in almost all cases, the average tine depth achieved was well below that required in the specification.

A review of the current literature and the results of a national survey conducted by NJDOT revealed a general dissatisfaction with bridge deck tining. This report recommends sawcutting as the preferred method for texturing bridge decks and makes specific recommendations for improving tining operations. A sample specification for sawcutting and the results of the national tining survey are presented as the Appendices.

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Mr. Sailey's assistance in the field portion of this study and Mr. Barros' counsel in the application of statistical techniques to the data analysis were invaluable and much appreciated.

IMPLEMENTATION STATEMENT

The bridge deck tining data collected during the course of this research gives convincing evidence that the quality of tining being achieved is less than acceptable. General dissatisfaction with the current tining specification, and the obvious need for an improved method of texturing bridge decks, has served as the impetus for this study and the recommendations contained herein.

The solution to this texture problem can be found by sawcutting grooves, in place of tining, on bridge decks. Sawcutting grooves will impart a more uniform, more durable texture resulting in a safer and longer lasting bridge deck surface.

This report recommends the adoption of the sawcutting technique for texturing bridge decks. The sawcutting specification included in the Appendix has met with favorable response from the operating divisions of the Department, as well as from the FHWA, and its adoption into the New Jersey Standard Specifications is imminent.

In the meantime, projects such as Route 287, Section 20B, 20C and 21B will be modified through the change order procedure, to include the sawcutting technique on bridge deck jobs as soon as possible.

As a matter of course, Research will work with Design, Construction, and field personnel in the early jobs specified for sawcutting, in order to assist in "fine-tuning" this technique and specification.

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1.0 OBJECTIVE

The objective of this research study was to examine the current method of imparting a textured finish to the deck surfaces of bridges being constructed and reconstructed in New Jersey and to develop improvements or alternates to the current practice if deemed necessary.

2.0 BACKGROUND

In early 1985, the Federal Highway Administration notified the New Jersey Department of Transportation's Bureau of Construction that, as a result of inspections-in-depth performed jointly with Department personnel during the 1984 construction season, the FHWA felt that the tine finishing being produced on our bridge decks was "inadequate in most cases".[1]

The Bureau of Construction contacted the Bureau of Transportation Structures Research and suggested a joint effort be undertaken to determine the magnitude of the deck tining problem in New Jersey and to develop specific recommendations for any needed improvements. This effort began with a review of the available literature on the subject coupled with inspections in the field to observe current practices and problems associated with achieving a satisfactory tined surface finish. This report discusses the results of the literature survey, responses to a deck tining questionnaire sent to all the states, as well as a number of measurements and observations made in the field at both new construction and existing older structures with tined decks.

3.0 STATE-OF-THE-ART

3.1 Literature Survey

An HRIS literature search revealed that since about 1978, a number of studies have been conducted regarding the use of tining or grooving to achieve improved skid resistance on bridge decks. Throughout this report and attached appendices, tining is defined as the texture produced in plastic concrete by combs or broom heads made up of metal or plastic tapes. Tining can be done by hand or mechanically. Grooving describes the finish produced by sawing grooves of the specified dimensions into hard concrete.

New York State in particular has published a large body of work on this topic. The findings of a 1983 New York Report[2] indicated that an increase of 1/16 of an inch in the specified minimum texture depth (i.e., from 2/16" to 3/16") would provide for an increase of 24% in the number of bridge decks which would maintain acceptable friction levels for the life of the structure. This was based on a New York design life of fifteen years and a wear rate of 0.01 inches per million vehicle passes. The New York investigators also assumed a minimum groove depth of 0.05 inches was necessary to provide an SN_{40} of 32 for tires at the legal tread wear limit. This value was obtained by testing surfaces with various groove depths with both smooth and ribbed tires and extrapolating between the SN_{40} vs. mean groove depth curves produced for an estimated tire tread depth of 2/32 inch (legal minimum).* Since the resultant curves displayed low correlations (R^2 of 0.11 for ribbed tires), the accuracy of the 0.05 inch minimum is questionable.

During the 1980 construction season, New York sawed grooves in two new bridge decks. This experiment was conducted in an effort to increase the life of the surface texture. The Federal Highway Administration encouraged these installations to determine if chlorides and moisture would penetrate the sawed concrete at a faster rate than with tined surfaces and whether sawing concrete early in its life would cause microfracturing of the surface. All sawed grooves were 3/16 +/- 1/16 inches deep, 1/10 inch wide, on 3/4 inch centers.

*New Jersey does not run skid tests with smooth tires. However, a considerable body of skid test data on New Jersey tined bridge and roadway surfaces suggests that little loss in skid number will occur using the standard ASTM E-274 Skid Test tire as long as any visible tining texture remains.

After three years of observation there was no evidence of an increase in scaling, nor was any fracturing discovered under microscopic examination. Ponding tests on cores taken from the decks, which represent a severe test of chloride permeability, indicated that after 90-day's exposure, chloride content was slightly higher within 1/2 inch of the bottom of the sawed grooves than under tined surfaces. At 1/2 inch or deeper, no difference was noted. Costs for sawcutting these decks ranged from $1.00 to $1.50 per square foot. It was estimated that with increased usage, costs would be in the .30 to .45 cent per square foot range.

In 1985 New York began specifying sawcutting as the standard finishing technique for concrete bridge decks. Prior to sawcutting the plastic concrete surface is textured with an artificial turf drag.

Virginia(3), Illinois(4), and Missouri(5) have also conducted research in the construction and measurement of tined surfaces. All agree that the surface imparted through tining produces better and longer-lasting skid resistance than broomed or burlap drag finishes.

3.2 Questionnaire Survey

In an effort to acquire an up-to-date picture of what is currently being done to texture concrete surfaces, a questionnaire was prepared and sent out to all the states. A response was received from forty-three of the fifty states. This large (86%) response is felt to be indicative of both the importance of this subject and the problems which have been encountered by the states. A copy of the questionnaire, together with a generalized summary and a tabulation of the responses, is included in Appendix A.

In general, the responses indicate that the great majority of states do require tining or grooving, or allow a choice of either as the final finish on their bridge deck surfaces. The responses to the questionnaire indicate that the maximum depth specified was 1/4 +/- 1/16 inch. Two states specify this depth. It is achieved on bridges in New York with a tolerance of +/- 1/16 inch by grooving. North Carolina also specifies a maximum 1/4 inch which is a tined finish. They do not indicate if they have any problem achieving this depth. The responses agree that tining results are quite variable and dependent on many factors. Chief among these are the quality of workmanship, uniformity of the concrete being textured, and the time of application.

Acceptance of the surface is very judgmental, usually based on overall appearance. A tire tread wear gauge is used by many agencies as a field tool for checking texture depth during and after construction. Other than sawing or grinding, the states surveyed have not developed any procedures for correcting an unsatisfactory tined surface.

3.3 Manufacturers' Survey

As part of the investigation, manufacturers of concrete finishing and texturing equipment were contacted in order to determine the current "state of the art" in equipment being used to mechanically texture bridge decks and roadway surfaces. Discussions with the manufacturers' representatives produced a definite indication that even with mechanical tining -- which entails the use of a tining head which traverses the concrete transversely under a finishing bridge -- the achievement of a 3/16 inch texture depth would be very much dependent on the same material uniformity requirements as govern hand texturing. The opinion was offered by one manufacturer's representative that "optimum conditions" would be necessary in order to consistently achieve a texture depth of 3/16 inch.

4.0 CURRENT NJDOT TINING PRACTICES

The New Jersey Department of Transportation currently specifies that the surface texture on bridge decks and concrete pavements shall be a tine finish having a uniform pattern of grooves perpendicular to the centerline, spaced at approximately 1/2 to 3/4 inch center, 1/8 to 3/16 inch deep, and 0.10 to 0.125 inch wide.

On bridge deck surfaces, mechanical devices are not required for tine finishes. On concrete roadway surfaces, a metal comb is specified which must be attached to a mechanical device capable of traversing the entire paving width in a single pass at a uniform speed.

All new decks on interstate routes, selected locations on state routes (e.g., heavy truck traffic, difficult to repair in future), and many rehabilitated decks are constructed with latex-modified concrete (LMC). LMC is mixed on site in a continuous mobile mixer. This type of an operation (volumetric proportioning) is not conducive to the production of a uniform mix. In addition, the design mix used for LMC allows a range of 0 to 6.5% air content and a slump requirement of 6.0 inch maximum. These broad limits can result in a highly variable mix on which it is difficult to consistently achieve an acceptable tined finish. The specification for LMC also requires that promptly after texturing, the overlay must be covered with a layer of clean wet burlap as soon as the surface will support it without deformation. White polyethylene sheeting is placed over the wet burlap within one hour. It is a judgment call as to when to place the burlap and sheeting so as to avoid damaging the tined surface and still begin the wet curing process as soon as possible.

On several deck construction jobs which were observed in the course of the investigation, it was noted that the application of the tined finish was not being done under the best of conditions. The work bridge used by the finisher applying the tining was also being used by other finishers doing touch-up and hand finishing operations behind the finishing machine. Often, the tine finishing man was doing other finishing operations in addition to the tining. In many cases, the tining operation seemed to be considered just something to be done before the burlap could be applied.

5.0 STUDY METHODOLOGY

5.1 Inspection of Bridge Deck Finishing Operations

In order to observe firsthand the procedures which are used in tining bridge deck surfaces, as well as the other operations in the bridge deck pour which might influence the texturing item, personnel from the Division of Research accompanied the Bureau of Construction inspection team on several inspections-in-depth during the 1985 construction season. These surveys were accomplished in order to familiarize Research personnel with the tining procedure and to get a sense of the tining quality being achieved in the field.

The structures which were observed were:

(1) Route 195, Section 1A, 1E, and 10D, Northeast span #2 Route 206 Bridge over Route 195, June 14, 1985.

The Route 206 bridge deck was constructed with Class A concrete. Placement was by means of 1-1/2 cubic yard buckets. Finishing was done with a Bidwell Roller Finishing Machine.

(2) Warrenville Road bridge over Greenbrook, Middlesex County, Greenbrook Township, June 26, 1985.

The Warrenville Road bridge was constructed with Class B-1 concrete. The concrete was pumped into place. Finishing on this structure was done with an Allen Vibratory Screed.

(3) Route 287, Sections 3M and 2L, Span #9, 287 N.B. over Easton Ave., August 16, 1985.

This bridge deck was constructed with an overlay of Latex Modified Concrete. Concrete was mixed in a Concrete-Mobile. A 1-1/4 inch overlay of the latex-modified concrete was placed over a previously placed 7-3/4 inch concrete deck. Finishing was done with a Gomaco roller finisher.

5.2 Measurement of Texture Depths on New Bridge Decks

5.2.1 Equipment

Although the general perception of Construction and Research personnel was that the tining achieved on new bridge decks was not conforming to the intent of the specifications (inadequate depth, lack of uniformity, appearance), no quantitative method of actually measuring bridge deck texture had ever been used to substantiate these feelings. The task of developing a quantitative method for measuring tining was undertaken by Research.

Information gathered in the literature review indicated that tire tread depth gauges have been used by many highway agencies as a convenient measuring device. Simplistic in form and function, the tire tread depth gauge (see Figure 1), incremented in thirty-seconds of an inch, turned out to be the ideal tool for measuring the depth of tining on hardened deck concrete. On a tined surface, the base of the gauge rests on the upper asperities of the surface, while the probe is inserted into the groove. The scale shows the depth of the groove in thirty-seconds of an inch.

5.2.2 Sampling Plan

A random sampling plan was then devised for the bridge decks selected for study. First, the bridge deck was divided into 10, 15, or 20 equal areas depending on the size of the deck and the number of individual slabs per deck. Within each area, a three-foot by three-foot test site was laid out, using a

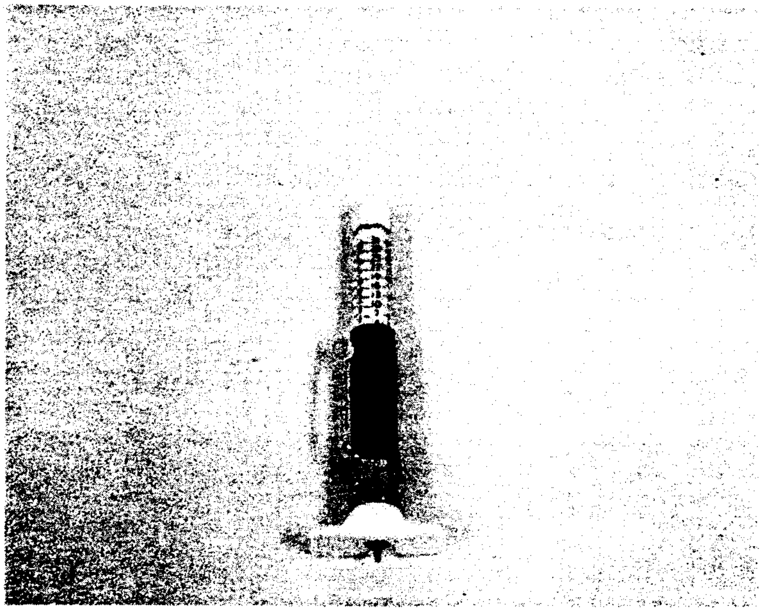


FIGURE 1

TIRE TREAD DEPTH GAUGE USED
FOR MEASURING TINE DEPTHS

random selection procedure. A straightedge was then laid across the diagonal of each test site, and tine depths were measured and recorded at ten equally spaced intervals along the diagonal.

5.3 Evaluation of Texture Wear Rates

In order to determine the minimum as-constructed depth of tining required to provide a skid resistant surface throughout the expected service life of a bridge deck, one assessment of the approximate loss of depth with time must be made. Random measurements of tine depth were made on twelve older bridge decks on Route 78 (7 years old, 5 years under traffic). Since no data was available for the as-constructed depth of tining, data was also collected on the shoulder of the bridge decks to be used as an approximate value for the tining prior to traffic wear. Original skid test values were available for these decks and skid tests were repeated this past summer for purposes of comparison.

6.0 RESULTS

6.1 Inspection Survey

6.1.1 Factors Investigated

Several bridge decks were observed during construction; Route 287-3M,2L (Easton Canal), Route 195-1A, 1E, and 10D (Route 206), and Warrenville Road Bridge. Several decks were inspected shortly after construction; Route 295-7G (Arena Drive and Kuser Road), and Route 78-4V, 5BM (Glenside Road), and Route 287-3M,2L (Weston Canal).

Research and Construction personnel collaborated in order to make general assessments of the quality of workmanship demonstrated by Contractor forces responsible for the tining portion of the deck construction. Likewise, the quality of the resultant tining was also subjectively rated on a four-point scale from excellent to bad. Factors which were considered in this assessment were uniformity of tining, portion of deck without texture, portion of deck having tears or pulls, and general appearance. It was hoped that the entire range from excellent to bad tined decks would be identified, so that when the tine depth measuring phase of the study was undertaken, a determination of the average tine depth for a good job, poor job etc., could be made.

6.1.2 Quality of Workmanship

In the opinion of the Bureau of Construction evaluation team on each of the bridge deck finishing operations observed in this study, the quality of workmanship was "Good"; that is, the workmen were performing the tining operation in accordance with specifications. The one exception to this was the Warrenville Road bridge, where workmanship was rated "Excellent"; that is, exceptional effort was made to ensure a high-quality tined finish.

The opinion of the Research personnel, having admittedly less experience with bridge deck finishing operations, was that in each case observed, except the Warrenville Road job, little effort was expended by the contractor to achieve the specified tine depth. It appeared that tining took place at a specified time (i.e., a fixed distance behind the finishing machine), regardless of the plasticity of the concrete. In one particular case, the latex-modified concrete appeared extremely variable, from truck-to-truck, and no effort was made to delay or hasten the tining operation to account for the material variation. Since "timing" is the key to "tining", this would seem to indicate a lack of appropriate concern or proper judgment. Pulling the tine rake across the surface seemed to be considered less important than applying the burlap covering, which was usually accomplished as soon as possible, regardless of the concrete being set enough to support the burlap without adhering. In some cases, the burlap became embedded in the finished deck, completely flattening the tined finish.

The materials and techniques used in bridge deck construction also affects the quality of tining achieved. Table 1 shows the materials, slump, air and any special notes for each of the bridge decks under study. The data for slump and percent air on latex-modified concrete decks indicates that most of the mixes were at the high end of the specification; six inches slump, six percent air.

6.1.3 Quality of Tining

Two bridge decks were rated "Good" - Route 295-7C (Kuser Road) and Warrenville Road Bridge. A "Good" rating indicated that the tining appeared relatively consistent throughout the deck; the tines appeared straight and deeper than usual. Few areas where the tining rake had only scratched the surface or had torn the concrete were present. Two decks, Route 195-1A, 1E, and 10D (Route 206 North and South) were rated "Fair". Route 295-7G (Arena Drive) North and South was rated "Poor". The texture was not deep and was fairly inconsistent with a number of very shallow areas. Route 287-3M, 2L (Weston Canal) and Route 78-5BN (Glenside Road) were rated "Bad". The Weston Canal Bridge exhibited severe tearing, due to tining after the concrete had begun to set. Many areas were observed with very shallow tining; several areas had burlap embedded in the surface.

The Glenside Road Bridge exhibited little to no tining in many areas, with burlap embedded in several places. It was reported that a sudden rainshower during construction necessitated premature covering with burlap and polyethylene. The weight of these materials, in conjunction with the rainwater, worked to flatten the tined texture.

TABLE 1

MATERIALS DATA ON BRIDGES OBSERVED IN STUDY

CONTRACT	LOCATION	TYPE OF CONCRETE	SLUMP(inch) AVG	SLUMP(inch) SPEC.	ENTRAINED AIR(%) AVG	ENTRAINED AIR(%) SPEC.	NOTES
295-7C	ARENA DR. SOUTH	LMC	6	6.0 max	5.8	0-6.5	Tining appeared
295-7C	ARENA DR. NORTH	LMC	6	6.0 max	5.8	0-6.5	variable.
78-5BN	GLENSIDE RD. WEST	LMC	6	6.0 max	6.0	0-6.5	Tines washed out and burlap embedded in surface.
287-3M,2L	WESTON CANAL	TYLAC LMC	5.3	6.0 max	6.3	0-6.5	Excessive tearing of concrete.
		POLYSAR LMC	3.4	6.0 max	5.1	0-6.5	Only used in gutters.
287-3M,2L	EASTON CANAL	TYLAC LMC	4	6.0 max	9.0	0-6.5	Shutdown when air reached 14%.
		POLYSAR LMC	5.3	6.0 max	5.5	0-6.5	Deck completed with POLYSAR.
195-1A,1E	RTE 206 NORTH	A	2-3	1-3	5.4-7.0	4.5-7.5	Tining of decks accomplished
10D	RTE 206 SOUTH	A	2-3	1-3	5.1-6.6	4.5-7.5	by only one workman.
295-7C	KUSER RD. EAST	B	3.2	1-3	5.9	4.5-7.5	Vibratory pan used on
295-7C	KUSER RD. WEST	B	3.2	1-3	5.9	4.5-7.5	finishing machine.
WARRENVILLE ROAD BRIDGE		B1	3.2	1-3	5.0-6.0	4.5-7.5	Concrete pumped and hand finished with vibratory screed.

6.2 Tine Depth Results on New Decks

Tine depths were measured with tire tread depth gauges, using a random sampling plan on a number of new bridge decks. These results are presented in Table 2. Distribution of the tine depths are presented in the histograms in Figure 2 and Figure 3.

All of the bridge decks, except the Weston Canal Bridge on Route 287, averaged from 2.4 to 3.4 thirty-seconds of an inch -- none met the current specification of 1/8 inch minimum. The Weston Canal Bridge was measured to average 4.1 thirty-seconds of an inch; 66% of the measurements taken on this deck were within specifications. However, due to the fragile appearance of these tines (concrete tears), it is not expected that this relatively good average tine depth will last very long under traffic.

An analysis of variance was conducted for all the new decks under study, excluding the outlier data from the Weston Canal Bridge on Route 287. Although a significant difference was found to exist between each of the seven bridges, no distinction was found between latex-modified concrete and portland cement concrete bridge decks as a group. Therefore, the data represents non-homogeneous population which cannot be analyzed as one data set, within the parameters of "good" statistics.

However, for discussion purposes, it has been observed that the mean tine depth for all seven bridges is 2.8/32 inch with a standard deviation of 1.2/32 inch. Likewise, the study indicates that 79% of the measurements taken were less than one-eighth inch and 80% were out of specification (1/8" to 3/16"). In point of fact, even on the Warrenville Road Bridge, considered by bridge deck inspectors to represent one of the best tining jobs in their experience, 67% of the measured data fell below one-eighth inch.

As a comparative note, even if the average tine depth achieved was normally distributed about the specified mean (5/32 inch), the variability of tine

TABLE 2

TINE DEPTH MEASUREMENTS ON NEW BRIDGE DECKS

CONTRACT	LOCATION	TYPE OF CONCRETE	TINE DEPTHS (1/32 in) RANGE	MEAN	STD.DEV.	% < 1/8"
295-7C	ARENA DR. SOUTH	LMC	0-7	2.9	1.2	72.0
295-7C	ARENA DR. NORTH	LMC	0-5	2.6	0.8	88.0
287-3M,2L	WESTON CANAL	LMC	0-9	4.1	1.6	35.5
195-1A,1E	RTE 206 NORTH	A	0-6	2.9	1.4	66.0
10D	RTE 206 SOUTH	A	1-6	3.1	1.2	66.7
295-7C	KUSER RD. EAST	B	0-8	2.6	1.0	82.0
295-7C	KUSER RD. WEST	B	0-5	2.4	1.2	89.0
WARRENVILLE ROAD BRIDGE		B1	1-8	3.4	1.4	66.7

TABLE 3

DURABILITY OF TINED BRIDGE DECKS

BRIDGE	AVERAGE TINE DEPTH OUTSIDE LANE 1/32 in	SHOULDER 1/32 in	ESTIMATE OF AVERAGE WEAR SINCE CONSTRUCTION 1/32 in
78 W #4	2.2	3.8	1.6
78 W #5	2.5	4.2	1.7
78 W #6	2.2	3.4	1.2
78 W #7	2.0	3.4	1.4
78 W #8	2.5	2.4	-0.1
78 E #2	1.3	3.0	1.7
78 E #3	2.1	2.7	0.6
78 E #4	1.6	2.0	0.4
78 E #5	2.1	3.3	1.2
78 E #6	2.2	2.4	0.2
78 E #8	1.3	2.9	1.6
1 S #1	1.2	2.7	1.5
1 S #2	1.3	2.5	1.2
195 W #1	2.3	4.5	2.2
195 W #2	2.2	4.1	1.9

FIGURE 2

DISTRIBUTION OF TINE DEPTHS - PCC DECKS

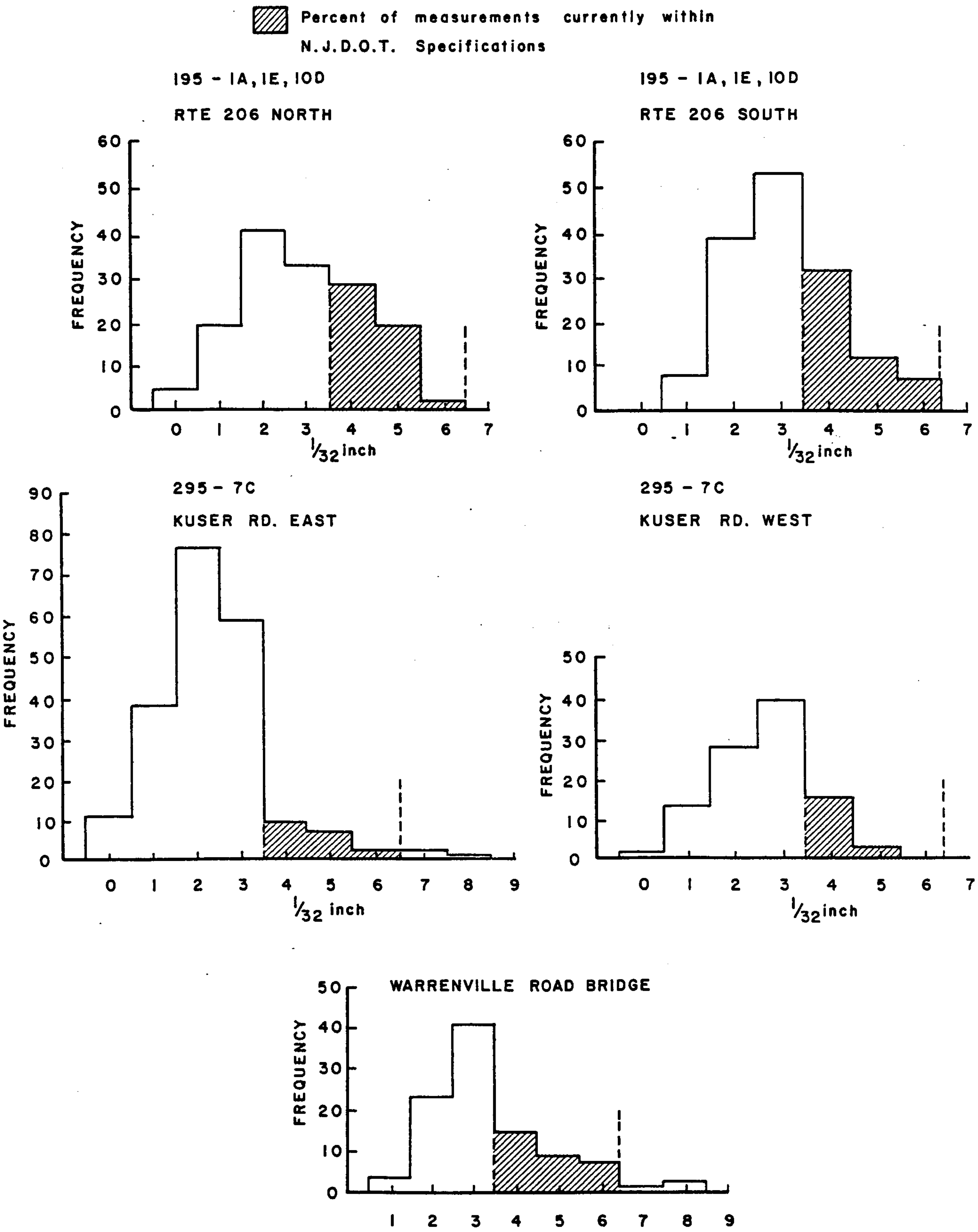
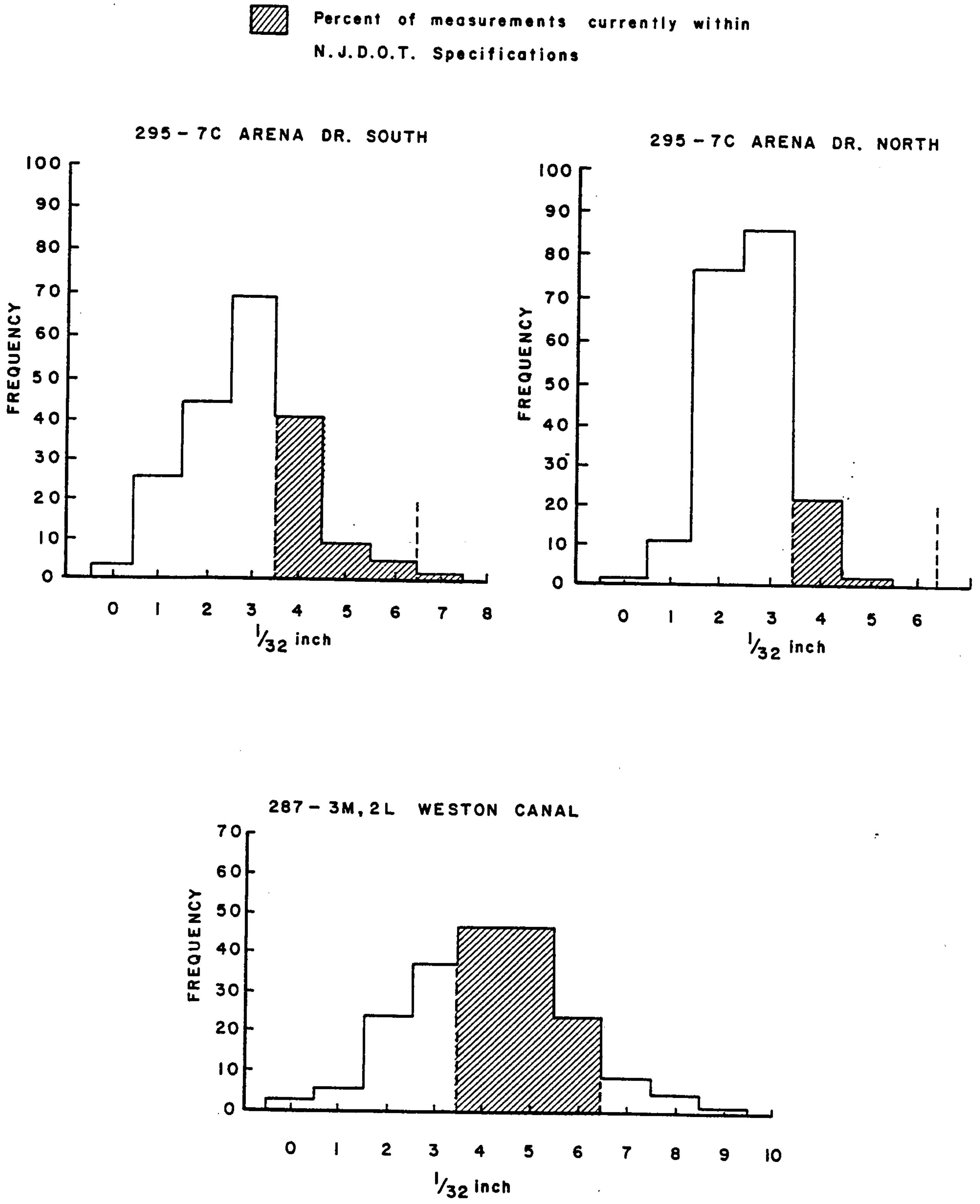


FIGURE 3

DISTRIBUTION OF TINE DEPTHS - LMC DECKS



depths are such that 20% of this hypothetical bridge deck would be below the minimum required depth and 40% would be out of compliance on both ends of the specification.

6.3 Wear Rates on Tined Surfaces

6.3.1 Tine Depth Measurements

For this portion of the evaluation, twelve LMC bridge decks on Route 78 constructed in 1978-79 were measured, using a random sampling technique. Since no data was available for tine depth at construction, measurements taken on the shoulder were assumed to be representative of the original tining. These results are presented in Table 3; histograms shown in Figure 4 show the distribution of average tine depths for all of the westbound and eastbound decks.

If the assumptions are made that tine depths will continue to decrease at the same rate as it has for the first five years under traffic, and that the life of the bridge deck is twenty years, at which time zero tine depth is acceptable, then the minimum required tine depth for a 63,000 AADT roadway with six traffic lanes (outside lane assumed to be 6300 vehicles per day) would be 4.4/32 inch. Table 4 shows the tine depth needed to ensure twenty years of service if these data were extrapolated.

In order to check these assumptions, two additional latex-modified concrete bridge decks were measured, the Pulaski Skyway (Route 1 SB) and Route 195 WB over Route 130. These two bridges were redecking jobs; the Pulaski Skyway was reopened in September, 1980 and Route 195 in September 1982. Summary tine depth measurement data is presented in Table 3 and illustrated graphically in Figure 5.

After approximately 5.25 years of traffic (38,200 AADT), the average wear rate was calculated to be 0.008 inches per year, very close to that measured on

FIGURE 4

DISTRIBUTION OF TINE DEPTHS ON RTE. 78

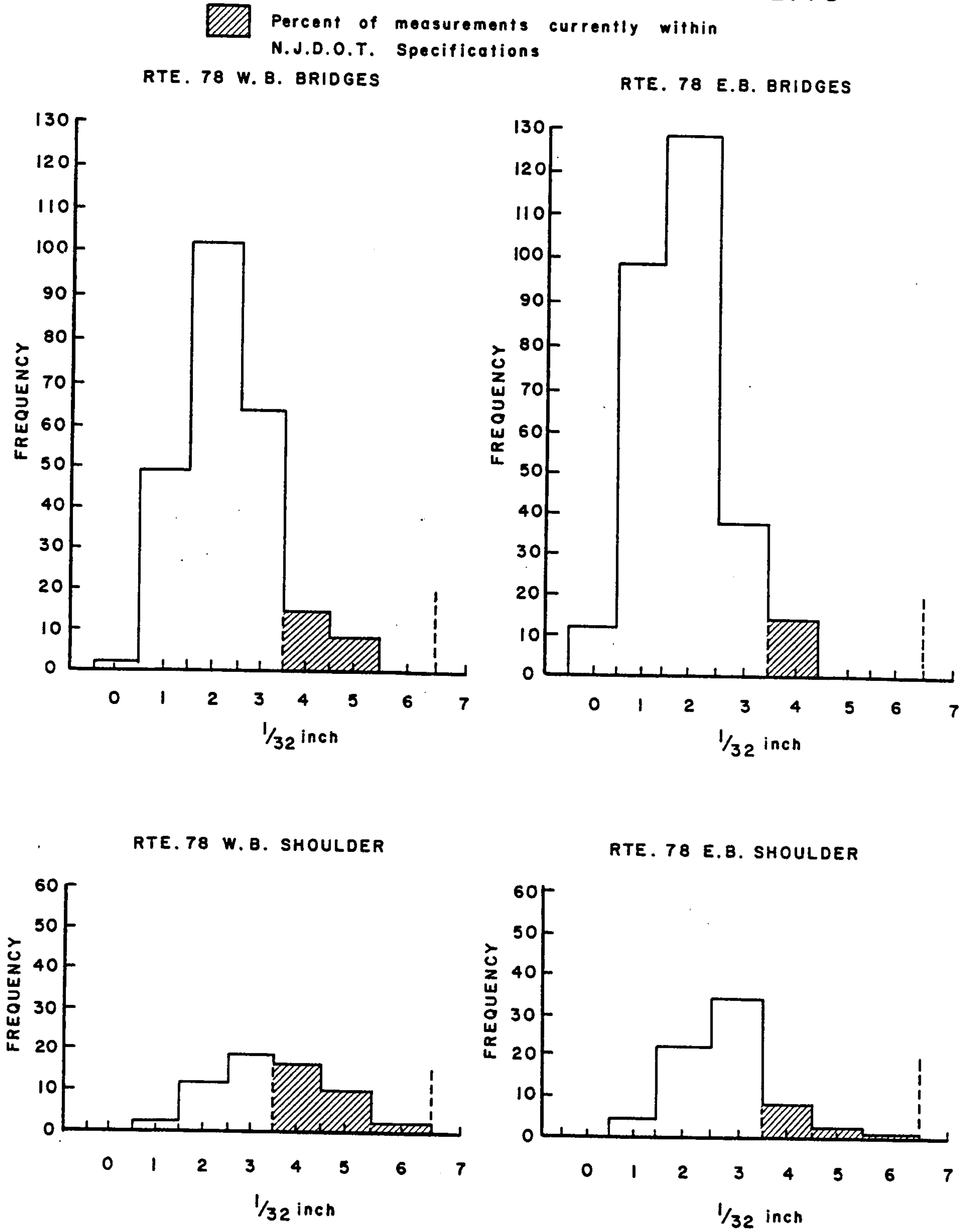
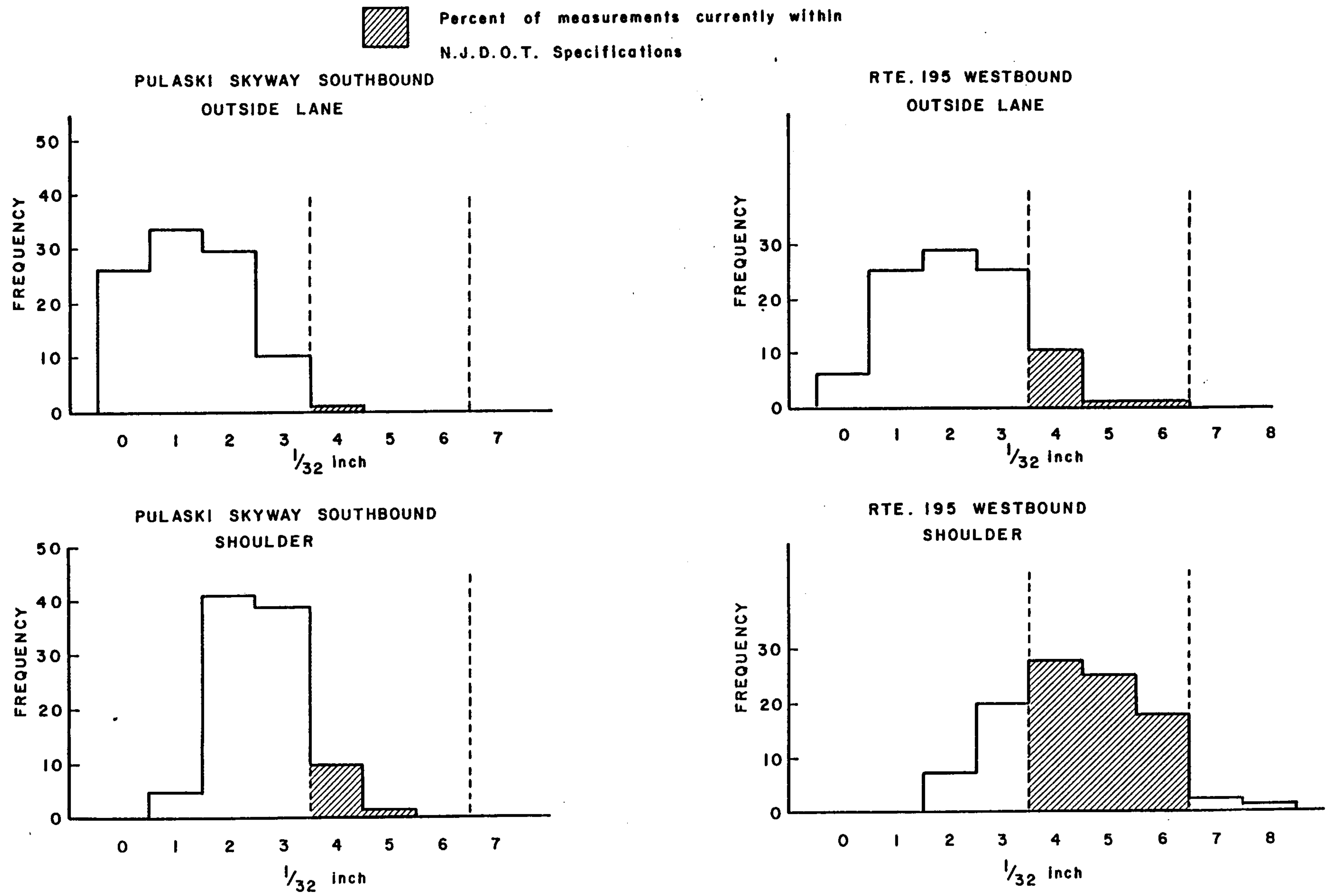


FIGURE 5

DISTRIBUTION OF TINE DEPTHS ON RTE. 195 AND THE PULASKI SKYWAY



Route 78 (.007 inches per year). Applying this wear rate over the life of a bridge deck yields the result that 5/32 inch of average tine depth would be sufficient at construction for this traffic level (see Table 4).

On the other hand, the data obtained from Route 195 indicated a much higher wear rate, therefore, a greater average tine depth needed at construction. This excessive wear rate may be due to exceptionally heavy construction traffic over this bridge deck during its 3.25 year life. A large amount of detritus from this construction traffic was observed on the bridge during the survey. The abrasive action of this material could lead to excessive erosion of the tined finish. One other factor which may explain the high wear rate on Route 195 is the general appearance of the tined deck. The Route 195 bridge deck has a very rough, jagged appearance, similar to that observed on the Route 287 - Weston Canal Bridge. This may be due to tining the surface after it had already begun to cure, leaving the surface torn and, therefore, more fragile.

Another factor to be considered is that the rate of wear on a bridge deck may not be accurately described as a linear function of its age, but rather as a logarithmic rate of decline. If this were indeed true, then a "younger" bridge deck like Route 195 would exhibit wear at a faster rate for some period of time. Regular measures of average tine depth over the life of the bridge deck would be required to confirm this.

Generally speaking, the results of this phase of this study, although admittedly based much on estimate indicate that the tining wear rate on these "older" bridge decks (5+ years) is from 0.007 to 0.008 inches per year. The data presented in Table 4 indicate that at least one-quarter inch of texture depth is required at construction for a bridge deck carrying 15000 vehicles per day per lane, in order to provide sufficient skid resistance over a twenty year design life.

TABLE 4

TINE DEPTH NEEDED TO ENSURE
20 YEARS OF SERVICE

VEHICLE PASSES PER LANE PER DAY	TINE DEPTH NEEDED AT CONSTRUCTION(in)
5000	3/32 - 4/32
10000	6/32 - 7/32
15000	8/32 - 11/32
20000	11/32 - 14/32
25000	14/32 - 18/32

TABLE 5

RESULTS OF SKID TESTS ON
RTE 78 BRIDGES

BRIDGE NUMBER	1980 SN40	1985 SN40
WEST #4	70	52
WEST #5	74	54
WEST #6	66	53
WEST #7	68	53
WEST #8	70	53
MEAN	70	53

6.3.2 Skid Tests on Tined Surfaces

Skid tests (ASTM E-274) using a grooved tire were conducted shortly after construction on five of the twelve LMC bridges under study on Route 78 and repeated in July, 1985. These results are presented in Table 5.

The results indicate relatively high skid resistance on the tined latex-modified concrete bridge decks over the five-year period since they were opened to traffic; decreasing an average of 16 SNs. It is difficult to make any prediction of skid resistance durability on tined decks, using grooved tire skid tests, since grooved skid tires are relatively insensitive to changes in perceived skid resistance which occur with changes in texture depth. It is sufficient to note that even at tine depths as low as 2.3 thirty-seconds of an inch, good skid resistance is exhibited on LMC bridge decks.

7.0 ALTERNATIVES

Since the texture depths currently being achieved are considered inadequate, there are several alternate approaches which should be considered.

7.1 Improve Current Practice

Contractor and state personnel responsible for the tining operation could be better educated as to the importance of the tining operation and its long-term effect on the skid resistance of the deck. Preconstruction meetings could serve as a forum for the discussion of the proper tining sequence and procedures. The use of simple depth gauges, such as were investigated in this study, would help insure that groove depth is adequate during the actual construction process. Such checks would enable timely corrective action to be taken.

A stricter interpretation of the specifications and the possible use of penalty clauses if textures did not meet the specified configuration could be considered. Some limited equipment modifications might also be effective. For example, stiffer tines and longer tines and the use of weighted heads on the tining tool should result in deeper groove depths. However, these options do not appear to offer any real promise.

7.2 Mechanical Tining

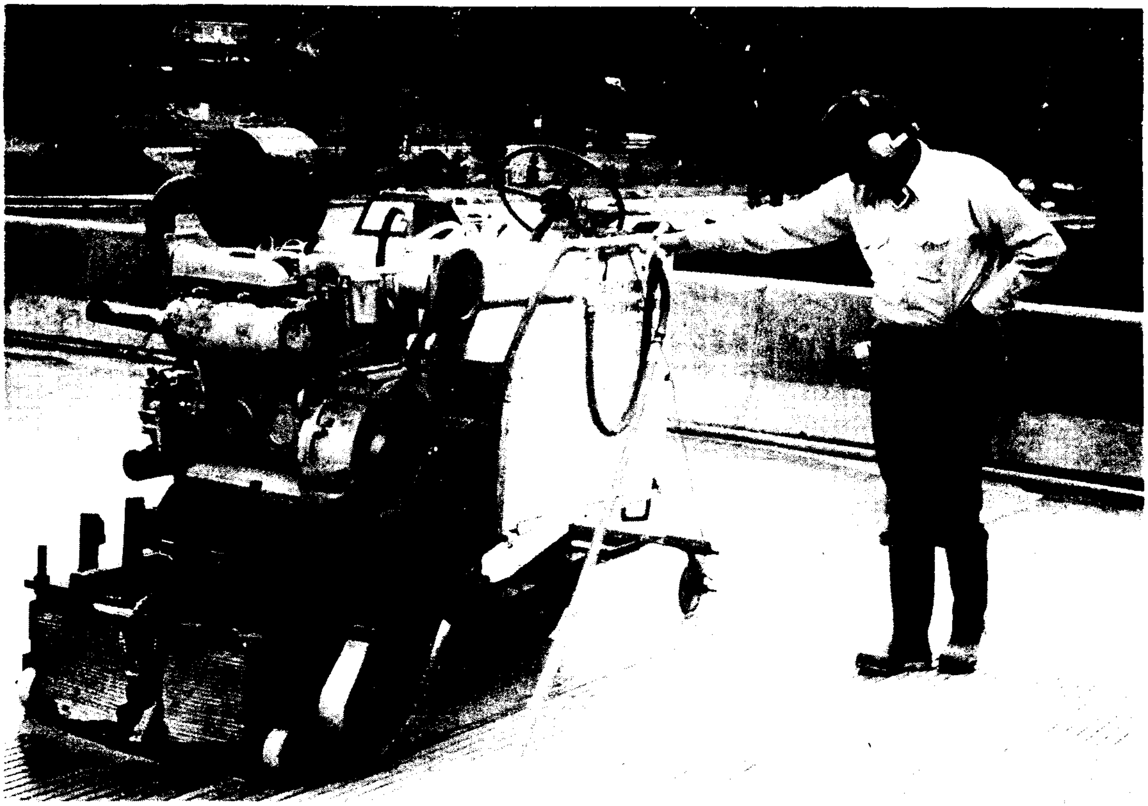
Tining combs which are mechanically moved transversely across the bridge deck surface while suspended under a truss similar to a finishing machine frame are routinely used to tine concrete roadway surfaces. Some checking of roadway surfaces, however, indicated that these devices do not consistently produce tine depths which meet the specifications. Discussions with representatives of the equipment manufacturers indicate that a depth of 3/16 inch is about the maximum that could be expected and would require optimum conditions, i.e., timing of application, concrete consistency, and concrete uniformity throughout the job. Observations indicate that these optimum conditions are unlikely to be achieved consistently.

7.3 Artificial Turf Drag and Saw Cut Finish

The finish achieved by sawcutting should be much more consistent than that which is achieved by tining because of the precise continuous control of the depth of cut. Deeper initial texture depths can be specified and achieved thereby producing longer lasting skid resistance. The sawcutting technique and the resultant texture is illustrated in Figure 6. Several added benefits can accrue with the use of this option. Improved riding quality should be achieved since the surface imparted by the finishing machine would not be disturbed and torn by the use of a tining tool. A time constraint imposed upon the contractor by the requirement to begin tining after the water sheen has disappeared and finish tining before the set has reached the point where tearing or roughening of the surface will occur, would be eliminated.

FIGURE 6

SAWCUTTING GROOVES IN BRIDGE DECK



Durability should be improved since the curing process could be started immediately without the need to delay application of the polyethylene and burlap until the tined texture would not be distorted by their application. Penetrating sealers may penetrate more effectively when applied to newly sawed surfaces.

A disadvantage of this procedure would obviously be the added cost of the sawcutting. Based on the New York State experience, the cost of sawing would be in the range of $1.00 to $1.50 per square foot initially. New York feels a reduction to 0.30 to 0.45 cents per square foot is reasonable with increased use of the procedures. Latest bid prices in New York State were in the .65 to .75 cent range going up to $1.00 in the New York City area.

8.0 CONCLUSIONS

1. An examination of the data collected on various bridge deck surfaces during this study indicate that the current specification of 1/8 to 3/16 inch of tine depth is not being achieved. Even on the Warrenville Road project, which was considered to be the most satisfactory tine finish observed by Bureau of Construction personnel in two years of in-depth inspections, the measured tine depths on the bridge deck were substantially less than the required minimum.

2. A preliminary study of texture wear rates on bridge decks indicates that even greater texture depth than is currently specified is needed to maintain a skid resistant surface over the bridge deck life. The results of this study show that one-quarter inch of texture would generally be sufficient to meet this criterion.

3. The tire depth gauge is a simple, inexpensive, and relatively accurate tool for the determination of tine depths in the field during construction. Texture depth in itself is not a sufficient measure of the quality of final finish on a bridge deck surface. Interpretation of the results must be tempered by

engineering judgment. Such factors as uniformity of finish, tearing and gouging, and durability of the final product must be considered.

4. The results of the questionnaire sent out to all the states indicate that tining is a problem nationwide. Dissatisfaction with the quality of tining typically achieved is universal, indicating that new methods for texturing bridge decks are in demand.

5. One option suggested to improve tining quality is the use of machine-tining equipment. However, since states which specify machine-tining are by and large dissatisfied with their results, and since even the equipment manufacturers are not optimistic, the use of machine-tining equipment does not seem to offer much promise at present.

6. The only procedure which has consistently produced satisfactory results is that currently specified in New York State -- sawcutting. New York State feels that the additional cost incurred by sawcutting is sufficiently offset by the uniform, high quality texture achieved on their new bridge decks.

9.0 RECOMMENDATIONS

1. Sawcutting to a minimum depth of one-quarter inch is the recommended procedure for bridge deck texturing. The use of this procedure will ensure the uniform texture depth required to last the life of the bridge deck.

2. Sawcutting, in accordance with the Sample Specification included in Appendix B, should be required in all bridge deck construction and rehabilitation projects.

3. In the interim, the use of the tire tread depth gauge is recommended to be used by inspection personnel to ensure the best achievable tine depth.

10.0 REFERENCES

1. FHWA Memorandum dated February 21, 1985 by John J. Kessler to Edward D'Arcy, Chief, Bureau of Construction.

2. RD-83/107 "Decay of Tine-Textured Grooves in Rigid Pavements" John E. Grady, New York Department of Transportation Report 1983.

3. Transportation Research Record No. 652 "Texturing New Concrete Pavements" Mahone, D.C., McGhee, K. H., McGee, J. G. G., Galloway, J. E. 1970.

4. FHWA/IL/PR-82-095 "A Study of PCC Pavement Texturing Characteristics in Illinois" Dierstein, P. G., 1982.

5. "An Investigation of Frictional Properties on Wire Combed PCC Pavement Surfaces" Missouri Highway and Transportation Department 1978.

APPENDIX A

RESPONSES TO QUESTIONNAIRE ON CONCRETE TEXTURING

QUESTIONNAIRE ON CONCRETE TEXTURING

1. What type of final finish do you require on your concrete bridge deck or concrete roadway surfaces?

Bridges: Tining 34 (79%) Grooving 16 (37%) Either 11 (26%)

Burlap Drag 10 (23%)

2. If tining or grooving is specified, what pattern do you require (depth of groove, groove spacing)?

Bridges: Maximum Depth: 1/4" 2 (5%), 3/16" 18 (42%),

1/5" 2 (5%), 1/8" 12 (28%), 1/16" 1 (2%), 1/20" 1 (2%)

3. Do you specify a specific type of equipment or construction practice (time of application, surface appearance, etc.) in order to insure that you are actually getting the desired configuration?

Surface Appearance 9 (21%) Other (47%)

Tine Dimensions 14 (32%)

4. In view of the variability of finishing which will be encountered under field conditions, what do you consider an acceptable job?

Engineering Judgment 14 (32%)

Conformance to Specifications 13 (30%)

5. Do you perform any tests either during or after construction to check the texture depth and pattern? If so, would you describe the procedure or tests which you are performing.

Visual Inspection 19 (44%) Depth Gauge 9 (21%)

Sand Patch 6 (14%) Reference Blocks 3 (7%)

6. Do you have any comments or suggestions?

See attached tabulation.

Concrete Texturing Practices 1985

Number of states responding: 43 (86%). The large response to the questionnaire is indicative of the concern nationwide related to the problem of achieving adequate surface texture on concrete and more specifically bridge deck travelled ways.

Responses to the various questions are summarized above and tabulated in the attached table.

BRIDGES

STATE	Grooving			Tining			Drag		
	W	S	D	W	S	D	W	S	D
ALABAMA					5/8-9/8	1/8			
ALASKA									
ARIZONA				x	x	x			
ARKANSAS									
CALIF.	1/8	3/4	3/16	1/8	3/4	3/16			
COLORADO									
CONN.				1/32	1/2	3/16			
DELAWARE									
FLORIDA									
GEORGIA	1/8	3/4	1/8						
HAWAII				3/32	3/4	3/16			
IDAHO									
ILLINOIS				1/10-1/8	3/4	3/16	x	x	x
INDIANA									
IOWA	x	x	x	1/8-3/16	3/4	1/8-3/16	x	x	x
KANSAS				3/16	3/4	1/8			
KENTUCKY					1/3-1	1/8-1/5			
LOUISIANA				1/8	1/2	1/8-3/16	x	x	x
MAINE				x	x	x			
MARYLAND	1/8	5/8-7/8	3/16						
MASS									
MICHIGAN				1/8	1/2	1/8			
MINN				1/32	1 1/2	3/16			
MISS							x	x	x
MISSOURI				1/10-1/8	1/2	1/8			
MONTANA				5/64	3/4	1/8-3/16			
NEBRASKA	x	x	x	1/8	1/2-3/4	1/8	x	x	x
NEVADA									
N.HAMP	x	x	x						
N.JERSEY				1/10-1/8	1/2-3/4	1/8-3/16			
N.MEXICO	1/8	7/8	3/16	5/64-1/8	7/8	.18			
N.YORK	1/10	3/4	1/4						
N.CAROL.				5/64-1/8	1/2	3/20-1/4			
N.DAKOTA				1/8	1/2-1	1/8-3/16			
OHIO				1/10	5/8	3/20	x	x	x
OKLAHOMA				5/64-1/8	1/2-1	1/8-1/4			
OREGON				1/8	3/4	1/8-1/4			
PENN									
R.ISLAND	3/16	3/4	3/16	3/16	3/4	3/16			
S.CAROL.		3/8-3/4	1/8	1/8	1/2	1/8			
S.DAKOTA		3/4-1	1/8	x	x	x	x	x	x
TENNESSEE	1/8	1/8-3/4	1/8	3/32-1/8	1/3-1	1/8-1/5	x	x	x
TEXAS	1/8	1/4-1/2	1/20	1/8	1/4-1/2	1/20			
UTAH	x	x	x	1/8	1/2-3/4	1/8			
VERMONT	x	x	x						
VIRGINIA				1/8	3/4	1/8			
WASH.				1/8	1/2	3/16			
W.VIRG.				3/32	1/2	1/8-3/16			
WISCONSIN				1/8	1	1/8-3/16			
WYOMING									

BRIDGES

STATE		Broom			Others	
	W	S	D	W	S	D
ALABAMA						
ALASKA	X	X	X			
ARIZONA						
ARKANSAS						
CALIF.						
COLORADO						
CONN.						
DELAWARE						
FLORIDA						
GEORGIA						
HAWAII						
IDAHO	X	X	X			
ILLINOIS						
INDIANA						
IOWA	X	X	X			
KANSAS						
KENTUCKY						
LOUISIANA						
MAINE				X	X	X
MARYLAND						
MASS						
MICHIGAN						
MINN						
MISS	X	X	1/16	1/32-3/32	1/2	3/16
MISSOURI						
MONTANA						
NEBRASKA	X	X	X			
NEVADA						
N.HAMP	X	X	x			
N.JERSEY						
N.MEXICO						
N.YORK						
N.CAROL.						
N.DAKOTA						
OHIO						
OKLAHOMA						
OREGON						
PENN						
R.ISLAND						
S.CAROL.						
S.DAKOTA		3/4-1	1/8			
TENNESSEE						
TEXAS	1/8	1/4-1/2	1/20			
UTAH						
VERMONT	X	X	X			
VIRGINIA						
WASH.						
W.VIRG.						
WISCONSIN						
WYOMING						

PAVMENTS

STATE	Grooving			Tining			Drag			Broom	
	W	S	D	W	S	D	W	S	D	W	S
ALABAMA											
ALASKA											
ARIZONA											
ARKANSAS											
CALIF.											
COLORADO											
CONN.				1/32	1/2	3/16	1/32	1/2	3/16		
DELAWARE											
FLORIDA											
GEORGIA				1/8	1/2	1/64-1/8					
HAWAII											
IDAHO					1/2						
ILLINOIS				1/10-1/8	3/4	3/16	x	x	x		
INDIANA											
IOWA	x			1/8-3/16	3/4	1/8-3/16	x	x	x	x	x
KANSAS				3/16	1/4	1/8					
KENTUCKY											
LOUISIANA				1/8	1/2	1/8-3/16	x	x	x		
MAINE											
MARYLAND											
MASS											
MICHIGAN											
MINN											
MISS											
MISSOURI				1/10-1/8	1/2	1/8					
MONTANA							5/64	3/4	3/4-3/16		
NEBRASKA							x	x	x		
NEVADA											
N.HAMP											
N.JERSEY				1/10-1/8	1/2-3/4	1/8-3/16					
N.MEXICO											
N.YORK				3/16	3/4	3/16					
N.CAROL.				5/64-1/8	1/2	3/20-1/4					
N.DAKOTA				1/8	1/2-1	1/8-3/16					
OHIO											
OKLAHOMA				5/64-1/8	1/2-1	1/8-1/4					
OREGON				1/8	3/4	1/8-1/4					
PENN				X	X	X					
R.ISLAND											
S.CAROL.											
S.DAKOTA	1/8			x	x	x	x	x	x		3/4-1
TENNESSEE				3/32-1/8	1/3-1	1/8-1/5					
TEXAS				3/32-5/64	1	1/8-3/16					
UTAH				1/8	5/8-7/8	3/32-5/32					
VERMONT											
VIRGINIA											
WASH.				1/8	1/2	3/16					
W.VIRG.											
WISCONSIN				1/8	1	1/8-3/16	1/8	1	1/8-3/16		
WYOMING											

STATE	EQUIPMENT Machine	Hand	Other	PAVEMENT TESTS Sandpatch	Depth Gauge	Other
ALABAMA	x	x				
ALASKA						
ARIZONA	x					
ARKANSAS						
CALIF.	x					
COLORADO						
CONN.	x				x	visual
DELAWARE						
FLORIDA						
GEORGIA	x			x		visual
HAWAII					x	x
IDAHO				x		
ILLINOIS	x	x		x	x	x
INDIANA						
IOWA	x	x			x	
KANSAS	x					visual
KENTUCKY		x		x		x
LOUISIANA	x	x	x		x	
MAINE						
MARYLAND	x					visual
MASS						
MICHIGAN						visual
MINN	x				x	visual
MISS	x	x			x	
MISSOURI						
MONTANA	x			x		x
NEBRASKA	x	x				visual
NEVADA						
N.HAMP						
N.JERSEY	x	x				visual
N.MEXICO						visual
N.YORK	x	x			x	dial-type
N.CAROL.		x				visual
N.DAKOTA						x
OHIO	x					x
OKLAHOMA	x	x				visual
OREGON		x				
PENN						
R.ISLAND	x	x				visual
S.CAROL.			x			x
S.DAKOTA		x				visual
TENNESSEE	x					visual
TEXAS	x	x		x		x
UTAH	x					visual
VERMONT						
VIRGINIA						visual
WASH.	x	x				visual
W.VIRG.						visual
WISCONSIN	x					visual
WYOMING						

STATE	COMMENTS
ALABAMA	
ALASKA	Most bridges have a.c. wearing course.
ARIZONA	
ARKANSAS	
CALIFORNIA	Deck coefficient of friction >or= 0.3 after finish.
COLORADO	Deck is usually a.c. over membrane
CONNECTICUT	
DELAWARE	
FLORIDA	
GEORGIA	No tining problem if concrete is good quality
HAWAII	Silicon reference sample
IDAHO	Reference blocks define texture depths
ILLINOIS	Hand tining permitted on bridge decks
INDIANA	
IOWA	Hand tining permitted on bridge decks
KANSAS	Finned float used for tining decks
KENTUCKY	
LOUISIANA	
MAINE	Stiff bristle texturing mat
MARYLAND	
MASSACHUSETTS	
MICHIGAN	Deficiencies corrected by sawing
MINNESOTA	Deficiencies corrected by sawing
MISSISSIPPI	Belt finish
MISSOURI	
MONTANA	Skid tests used as control
NEBRASKA	Broom finish permitted on decks
NEVADA	
NEW HAMPSHIRE	Membrane used with bituminous overlay
NEW JERSEY	Hand tining primarily on bridges
NEW MEXICO	
NEW YORK	Spec pending change to 100 % saw grooving
N.CAROLINA	
N.DAKOTA	Ruler and straightedge used to check tine depth
OHIO	Flexi-guide tine used
OKLAHOMA	Hand tining permitted where mechanical cannot be used
OREGON	
PENNSYLVANIA	Grind and groove to correct deficiencies
R.ISLAND	Large decks are sawcut
S.CAROLINA	
S.DAKOTA	Tining to be specified in near future
TENNESEE	
TEXAS	Test panels used to train inspectors
UTAH	
VERMONT	
VIRGINIA	
WASHINGTON	
W.VIRGINIA	
WISCONSIN	Turf drag in urban areas, tining in rural.
WYOMING	

APPENDIX B

SAWCUT GROOVED DECK FINISH SPECIFICATION

501.15 Deck Slab Surface Texture Finish. The surface of the deck slab shall be finished in accordance with Subsection 405.13 except that part (g) shall not apply. All concrete bridge deck slabs shall be textured with an artificial turf drag and shall be sawcut groove finished.

(a) Turf Drag. Immediately after finishing has been completed, the surface shall be given a texture with an approved artificial turf drag. The drag shall be made of molded polyethylene with synthetic turf blades approximately 0.50 inches long. There shall be approximately 6,000 blades per square foot.

The drag shall be operated in a longitudinal or transverse direction. Once begun, the direction of texturing shall not change. Texturing shall be done from a work bridge.

When texturing is done in the longitudinal direction, the turf drag shall be a single, full-width strip. Small areas otherwise inaccessible to the full-width drag may be textured by hand methods.

The turf drag finish shall be applied so as to prevent ridges or gouges from forming in the concrete surface. The drag shall be weighted and the contact area changed as required to produce a uniform texture. The drag shall be cleaned periodically to remove all hardened concrete particles. Texture resulting from the drag shall stop within one foot of curbs.

(b) Sawcutting. The bridge deck concrete shall be cured in accordance with Subsection 405.14. Sawcutting shall not be permitted until the concrete on the deck has attained a strength of at least 3000 pounds per square inch as determined from cylinders cast during the placing of the concrete deck and is at least 14 calendar days old. Unless otherwise approved, sawcutting shall be completed prior to opening to traffic.

(c) Sawcut Grooved Surface. The hardened surface of concrete bridge deck slabs shall be grooved except at the locations shown in Table 501-A.

A plan of action shall be submitted for approval, seven days prior to sawcutting, detailing the layout of the grooving procedure to be followed. Spacing dimensions at the starting and ending point of each pass shall be noted. A description of the sawcutting equipment shall be included.

Grooves shall be cut perpendicular, or radial, to the centerline of the roadway. Radial grooving shall be conducted in partial width passes. Each pass shall be limited to one lane width. Adjustment along the longitudinal axis of the bridge deck shall be made at no less than twelve foot intervals, yielding a uniformly grooved surface finish.

Grooves shall be rectangular in shape. They shall conform to the following dimensions:

Width............... .1" to .15"

Depth.............. .25" to .375"

Grooves shall be spaced at 1.5" plus or minus .0625" center-to-center of groove. This spacing dimension may be increased up to 3" at the end of each consecutive multiple bladed saw cut pass as necessary to accommodate the distance tolerance required at the joint system (see Table 501-A). The required dimension will be determined prior to actual deck grooving and shall be stated in the plan of action. The cutting of grooves over an area which has already been grooved will not be permitted. No cutting blade shall be introduced into an already established groove. When it is necessary to rotate the sawing equipment to complete grooving to within the tolerances specified in Table 501-A, the longitudinal gap created shall not be located in a wheelpath and shall not exceed 3" in width.

Grooves shall terminate within the following limits.

TABLE 501-A

Location	Closest Allowable Distance	Farthest Allowable Distance
Drainage Structure	1' - 0"	1' - 3"
Vertical face (curb or parapet), or face of railing (no curb)	1' - 0"	1' - 3"
Joint System	6"	See Note

Note: This distance is a variable which is dependent upon equipment size. This dimension shall be measured perpendicular to the direction of the grooves. The distance shall be measured from the edge of the joint system and in no case should be greater than the width of the saw head plus nine inches tolerance.

Grooves shall be constructed using multibladed sawcutting equipment, fitted with diamond-tipped circular saw blades, except when the Engineer permits the use of single blade circular saw equipment where he determines such equipment is necessary to complete the work as required.

Prior to grooving operations, the Contractor shall supply two approved gauges to verify groove depth. The gauges shall be accompanied by manufacturer's instructions for their use.

During the grooving operations, the groove dimensions will be checked at random. If the minimum groove depth is not being achieved, the Contractor shall stop grooving operations and make necessary adjustments.

Slurry from the grooving operation shall not be permitted to accumulate in the grooves. Slurry or debris shall not be disposed of in the structure or highway drainage system nor on the roadway slopes. Slurry shall be promptly collected and removed for disposal off-site.

Sidewalks and top of curbs shall receive their final finish with a fine bristled broom.

501.25 Method of Measurement

The following is added:

The sawcut grooved deck surface will be measured by the square foot of deck, less the ungrooved gutter areas.

501.26 Basis of Payment

The following is added:

<u>Pay Item</u>	<u>Pay Unit</u>
Sawcut Grooved Deck Surface	Square Foot

Add to 405.03 Equipment after (f)

Multibladed Circular Saw: When sawcutting grooves is specified, sawing equipment shall be provided. The saws shall be of a multibladed type, adequate in number of units and power to complete the sawcut grooving operation, equipped with water-cooled, circular, diamond edge blades and alignment wheels. A system of slurry collection shall be provided. An ample supply of replacement saw blades shall be maintained at the work site at all times during grooving operations.