MILLABRADING TEST EVALUATION

Norwood Road – M.P. 287.02 (Southbound Interstate 5)

Construction Report

FHWA-OR-RD-00-02

by

Liz Hunt, P.E.

for

Oregon Department of Transportation
Research Group
200 Hawthorne SE, Suite B-240
Salem OR 97301-5192

and

Federal Highway Administration
Washington, D.C. 20590

September 1999

1. Report No. FHWA-OR-RD-00-02	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Millabrading Test Evaluation Norwood Road – M.P. 287.02 (Southbound Interstate 5) Construction Report		5. Report Date September 1999 6. Performing Organization Code
7. Author(s) Liz Hunt, P.E. ODOT Research Group		8. Performing Organization Report No.
9. Performing Organization Name and Address Oregon Department of Transportation Research Group 200 Hawthorne SE, Suite B-240 Salem, Oregon 97301-5192		10. Work Unit No. (TRAIS) 1. Contract or Grant No. FHWA Special Project 205
12. Sponsoring Agency Name and Address Oregon Department of Transportation Research Group 200 Hawthorne SE, Suite B-240 Salem, Oregon 97301-5192 and Federal Highway Administration Washington, D.C. 20590		13. Type of Report and Period Covered Construction October – November 1998 14. Sponsoring Agency Code

15. Supplementary Notes

The project was funded through the FHWA-sponsored *Quality Concrete Pavement Rehabilitation and Preservation* program.

16. Abstract

The Oregon Department of Transportation (ODOT) continues to investigate alternatives for rehabilitating the rutting in concrete pavement sections. The millabrading system was proposed as an option to reduce the middle lane rut depths in a continuously reinforced portland cement concrete pavement to improve driving conditions. Rut depths of 19 to 32 mm were measured prior to construction. The system includes a high speed rotomill with a modified drum used to level out the ruts, followed by a shotblaster with steel shot to provide a uniform, skid resistant wearing surface.

The following conclusions were reached following an eight-month investigation.

Construction noise levels should be considered if the grinding is to take place near a residential area. Air quality, particularly coarse particulate fallout may be a problem if the rotomilling is done for an extended period in one area.

A post construction inspection measured random rut depths of 10 to 16 mm in the middle lane. Some rutting was expected, however, not to the degree measured. Insufficient survey data may have impacted the design and subsequent outcome. Full-width treatment may have eliminated the ruts. In addition, the longitudinal joints appeared spalled. A petrographic analysis indicated that there is no micro-cracking that may be detrimental to the durability of the section. Accident data for comparison between the before and after conditions is not currently available. District Maintenance staff report no problems with the section.

Field test results indicate that in-vehicle noise levels are noticeably lower after construction. Because some of the pavement ruts still remain, the reduction in noise is dependent on where the tires hit in the lane. Pavement friction values increased following the grinding and additionally after the shot blasting. Friction values, however, have continued to decrease for the last eight months following construction. The pavement ride or roughness appears to be slightly reduced following the millabrading process. Again, since some rutting still remains, the IRI reductions are dependent on where the roughness is measured.

Recommendations for future use are included.

17. Key Words PCC, Pavement Rehabilitation, Grinding, Shot Blasting, Rut Removal, Rotomill	18. Distribution Statement Copies available from NTIS

19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages	22. Price

Technical Report Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

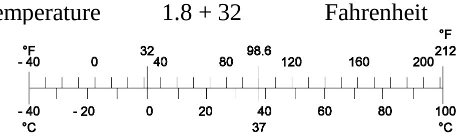
SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8 + 32	Fahrenheit	°F



* SI is the symbol for the International System of Measurement

(4-7-94 jbp)

ACKNOWLEDGEMENTS

The author would like to thank Bruce Council, Luci Moore, Walt Bartel from ODOT; Jeff Graham and Ivan Marrero from FHWA; and Eric Lindquist and Tony Halton of Shot Surfacing Incorporated for their efforts in coordinating the project and reviewing the report.

DISCLAIMER

This document is disseminated under the sponsorship of the Oregon Department of Transportation and the United States Department of Transportation in the interest of information exchange. The State of Oregon and the United States Government assume no liability of its contents or use thereof.

The contents of this report reflect the views of the author who is solely responsible for the facts and accuracy of the material presented. The contents do not necessarily reflect the official views of the Oregon Department of Transportation or the United States Department of Transportation.

The State of Oregon and the United States Government do not endorse products of manufacturers. Trademarks or manufacturers' names appear herein only because they are considered essential to the object of this document.

This report does not constitute a standard, specification, or regulation.

MILLABRADING TEST EVALUATION

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

The Oregon Department of Transportation (ODOT) continues to investigate alternatives for rehabilitating concrete pavement sections. Of particular interest is the section of Interstate 5 (I-5) between Salem and Portland. Studded tire use has resulted in wheel path ruts on the three-lane section creating potentially hazardous driving conditions. The most severe ruts, ranging from19 mm to 32 mm deep, occur in the middle lane.

The millabrading system was proposed as an option to improve driving conditions by reducing the middle lane rut depths. The system includes a high speed rotomill with a modified drum used to level out the ruts, followed by a shotblaster with steel shot to provide a uniform, skid resistant wearing surface. The *Millabrading Test Evaluation* project was set up to demonstrate and evaluate the system for removing ruts on PCC pavements.

The project was funded through a Federal Highway Administration (FHWA) program: *Quality Concrete Pavement Rehabilitation and Preservation* (Special Project 205). SP-205 was established to evaluate, among other things, the performance of individual rehabilitation and maintenance strategies for portland cement concrete (PCC) pavements. The ODOT millabrading project documentation will be combined with findings from other states to be published later in 1999 by the FHWA.

2.0 BACKGROUND

The I-5 test section was constructed using the millabrading system, which included a high-speed rotomill with a modified drum followed by a shotblaster. The work was done in the southbound lanes of I-5 between Tualatin and Wilsonville from Norwood Road, M.P. 287.52 to M.P. 287.02 (about 0.8 km). The vicinity and location are shown in Figures 2.1 and 2.2. The goal of the project was to remove or at least significantly reduce the ruts in the center lane of the three-lane PCC pavement section.

2.1 EXISTING CONDITIONS

The southbound section of I-5 is three lanes wide with 3.7 m lanes. The existing pavement consists of 200 mm of continuously reinforced concrete pavement over aggregate, built in 1971. The existing concrete pavement slopes to the outside shoulder at a slope of about 2%.

The Oregon Pavement Management System condition report rates the section as being in generally good condition *(ODOT 1998)*. Because the rating is done in the truck lane, only low severity rutting was noted. Low and moderate severity transverse cracking was noted, along with low severity distress at the longitudinal joints. The low severity distress indicates that the joint is in good condition. Rut depth measurements taken in the middle lane as part of this project, measured 19 to 32 mm deep.

Traffic volumes range from about 132,000 ADT at the Nyberg Road interchange (Tualatin) to 103,000 ADT at the Wilsonville interchange. The traffic counts include traffic in all lanes, both directions. The average precipitation is about 900 mm per year with average daily temperatures between -5 and 31° C.

2.2 PROJECT DESIGN

Project limitations required that minimal grinding would take place in the slow (truck) lane. ODOT Pavement Services was concerned about reducing the structural support from that lane since it is already showing signs of distress such as the low to moderate severity transverse cracking previously noted. To minimize impacts to the slow lane, the project was designed to start the grinding on the upper slope of the pavement (in the fast lane), making three passes with the third pass daylighting in the left wheel path of the truck lane.

The design cross sections are shown in Figure 2.3. A minimum cross slope of 1% was set to maintain drainage. A maximum cross slope of 3% was allowed. Approximately 16 mm of PCC pavement would be removed. Project monitoring included identifying any impacts associated with creating a broken slope in the middle lane. Would the different slopes affect automobile handling and/or increase accident frequency?

Figure 2.1: Vicinity Map

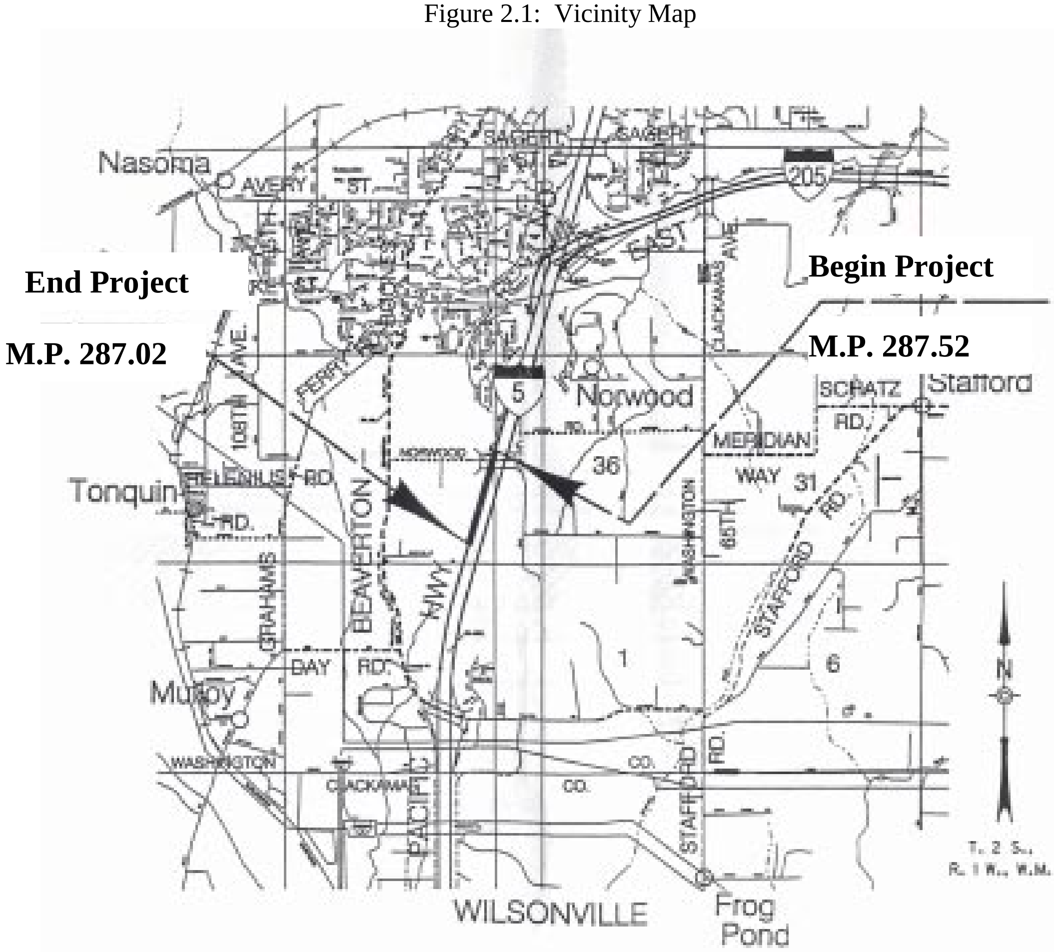


Figure 2.2: Location Map.

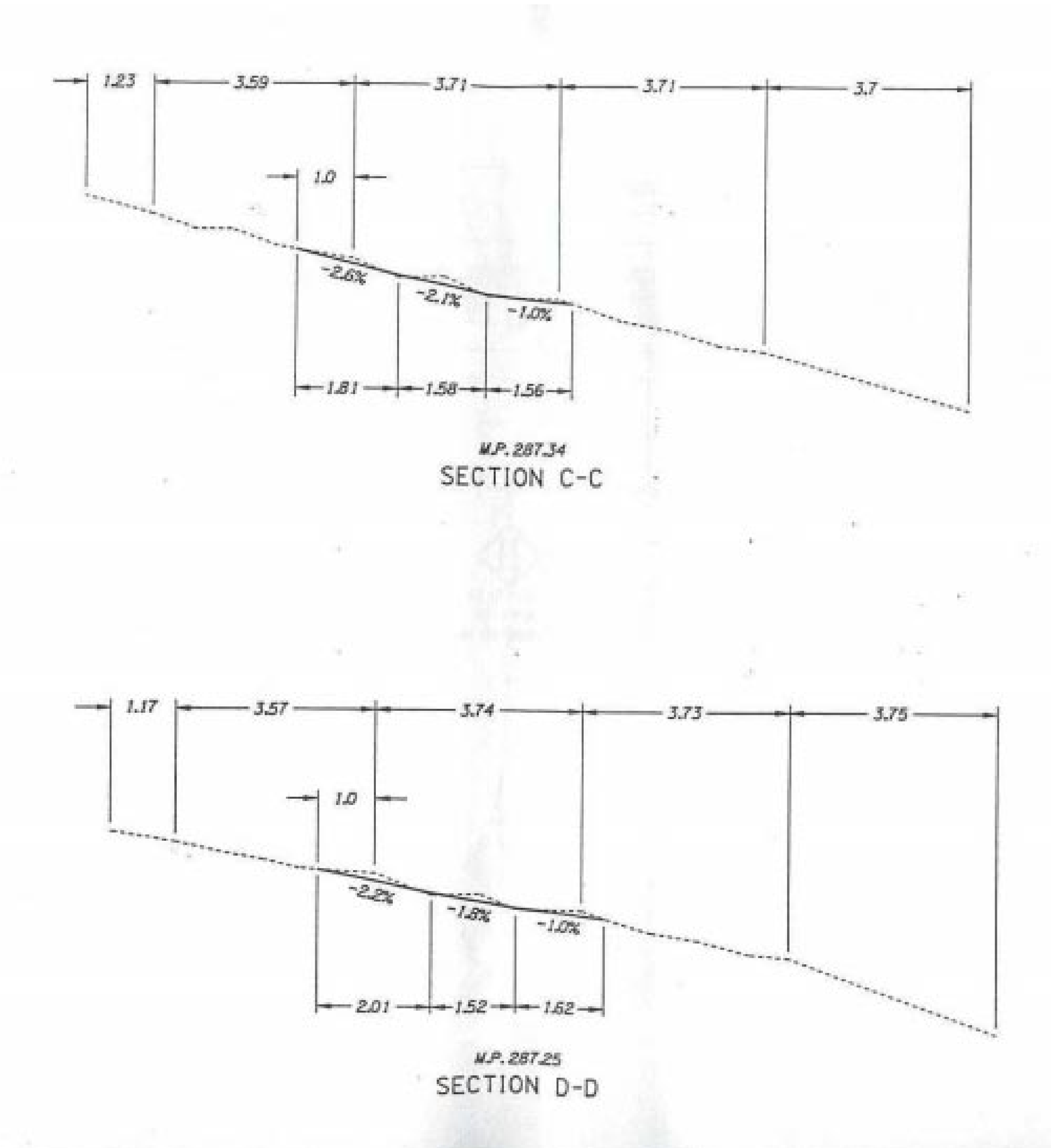


Figure 2.3: Design Cross Sections

2.3 PREVIOUS STUDIES

2.3.1 ODOT State Planning and Research Projects

Several ODOT State Planning and Research (SPR) projects have been initiated to study concrete pavement conditions and options for repair, including:

- *Rigid Pavement Performance Data*, 1993: A study done to collect information on rigid pavements in Oregon in order to judge performance.
- *Repair of Rutting Caused by Studded Tires*, 1995-present: A study underway that includes a literature review of possible treatment methods and an evaluation of the dominant factors that affect road wear, an evaluation of aggregate properties that reduce wear, and possible aggregate test methods.
- *Repair of Studded Tire Damage, I-5 Pilot Project*, 1996: A study done to monitor the construction and performance of a full-width asphalt concrete overlay on concrete between Salem and Portland. Four types of AC materials were tested.

As shown by the emphasis placed on research into rehabilitative strategies for PCC pavements, ODOT is very interested in identifying solutions to studded tire wear.

2.3.2 WSDOT Demonstration

In 1996, the Washington Department of Transportation rehabilitated a 305 m section of PCC on I-90, eastbound at about MP 56 in the slow lane. The project was Hyak Vicinity to Ellensberg – Phase 1. The 200 mm non-reinforced pavement had 6 to 12 mm of joint faulting and an additional 6 mm of wear in the wheel paths. A rotomill with a modified drum was used, with a tooth spacing of 4.52 mm. Production rates ranged from 420 to 1000 m^2/hr.

Spalling was noted on the transverse joints where the drum overlapped in the center of the lane. It was noted that using a smaller-width drum to minimize overlap could alleviate the spalling. The project also demonstrated that the milling drum cut the aggregates but did not pull them out. Smoothness and friction resistance were improved following the process *(Lindquist 1996)*.

Recent discussions with WSDOT indicate that they would not specify the modified rotomill on future projects with jointed PCC because of the spalling at the transverse joints *(Pierce 1999)*.

2.3.3 ODOT Concrete Profiling Project

In February 1990, ODOT rehabilitated a section of PCC pavement on I-5 (Delta Park - Marquam Bridge Section) also using a modified rotomill. The construction is documented in the Construction Narrative Report *(Villalpando 1991)*. The project had been designed using a diamond grinder, however, the modified rotomill was proposed as an alternative to increase production. The modified drum tripled the number of carbide teeth per block with a spacing of 6.35 mm. Overall, the rotomilling provided a fast and economical process for rut removal.

The Construction Narrative discusses the effects of diamond grinding and rotomilling. Cores taken in areas rehabilitated with both processes were evaluated for distress. Neither machine appeared to cause damage to any significant depth. The diamond ground cores, however, showed slightly more cracked aggregate while the rotomilled cores had more aggregate popouts.

Production rates for the diamond cut section were about 90 m^2/hr. Production rates for the rotomilled section averaged about 280 m^2/hr. As the rotomilling process continued, downtime increased to replace teeth and perform general maintenance.

The sweeper used with the rotomill was unable to adequately clean up the resulting dust and cement residue. The outside lane was cleaned with pressurized water, however, this was not possible on the inside lanes since the water run-off would impact the lanes under traffic. If the section was not cleaned up, there would be a potential for latent cement from the grinding residue getting into the storm sewers which could lead to drainage problems. The diamond grinder on the project was equipped with a high-pressure vacuum, which picked up the water and any particles generated.

The rotomilling led to spalling of both the longitudinal and transverse joints. No spalling was noted with the diamond grinding. Several techniques were tried with the rotomilling to minimize the spalling. A grout filler placed prior to grinding over transverse joints worked best but added labor since the grout was chipped out prior to placing a sealant into the joint. The extra time required was easily compensated for by the time savings with the higher production rate of the rotomill. Compared to diamond grinding, the rotomilling was found to be a faster and more economical process.

2.4 SCOPE OF REPORT

The *Millabrading Test Evaluation* report includes a construction discussion including equipment used, production rates, and noise and air quality impacts in Chapter 3. Pre-construction and post-construction conditions of the PCC pavement are documented in Chapter 4. Conditions monitored included surface condition, in-vehicle noise levels, skid resistance, roughness, and accident history. Comparisons with diamond grinding and asphalt concrete (AC) overlays are made in Chapter 5. Finally, conclusions and recommendations are presented in Chapter 6.

3.0 CONSTRUCTION PROCEDURES AND MONITORING

The contractor for the millabrading project was Shot Surfacing Incorporated of Portland. Construction was originally scheduled for September 1998, but due to contracting problems, construction did not start until October 27th, 1998. The last of the shot blasting was completed on November 9th, 1998. To accommodate the traffic volumes, single lane closures were only allowed from 7:00 pm until 6:30 am. Two-lane closures were allowed from 11:00 pm to 5:00 am. The following sections describe the construction operations. Selected portions of the special provisions are included in the Appendix.

The air temperature for the duration of construction varied between 5° C to 11° C. Generally, the nights were very humid with light showers creating a wet pavement.

3.1 MILLING

The milling process utilized a rotomill built by CMI out of Oklahoma City, model PR-800-7. The machine weighed 33.6 Mg and operated at 597 kW. Modifications to the unit included a modified drum speed, automated grade control skis, and a custom built drum. MillCo, also out of Oklahoma City, manufactured the drum. The 2.1 m wide drum provided a tooth spacing of 4.5 mm *(Halton 1999).* The rotomill is reported to operate at about 6 m/min over a 2.1-m wide path. Based on discussions with the contractor, machine weight and drum speed, along with tooth spacing were found to be critical to the effectiveness of the milling. Figure 3.1 includes a photograph of the modified drum.

Figure 3.1: Modified Rotomill Drum

During milling, there were six pieces of equipment on site including the rotomill, water truck, mechanical sweeper, vacuum sweeper, and two dump trucks to haul the millings from the rotomill. The tailings were loaded into the truck through a conveyor belt. There were four workers with the rotomill including an operator and three laborers on the ground.

A 15 m taper was included at the beginning of the job to minimize the bump from the rutted section to the milled section. The first section milled was the outside wheel path of the fast lane, followed by the right wheel path of the middle lane and finishing with the left wheel path of the middle lane and the left wheel path of the slow lane. After each pass, the mill was moved back to the beginning of the project and started again in the direction of traffic (southbound).

The first pass covered a non-filled joint. Spalling was noted in the joint, which could be a problem in the future. A filled joint, milled the second night, did not appear to spall as much as the first. The ideal system would be to mill to the joint then move just beyond it for the next pass. Unfortunately, the joint on the first pass was in the middle of the 2.1 m path. An additional concern with the joint is the possibility for reflective cracking if the pavement is overlaid, which would be the next logical rehabilitation strategy.

The first pass also included the replacement of a broken tooth. The operator noticed a groove in the pavement indicating a missing tooth. It was quickly replaced. The teeth were completely replaced prior to the second night of construction due to wear. To keep the milled pavement uniform, the teeth need to be uniform, however, they do not wear evenly. Uneven wear occurs on the teeth as they mill over the high spots between the ruts. Measured rotomill production rates over the course of the project varied from 5.5 m/min to 7 m/min for a 2.1 m path.

The specifications required that the cross slope be maintained at 1% minimum and 3% maximum. The resulting cross slope for the first pass was measured between 2.2 to 2.9% using a "Smart Level". Subsequent cross slope measurements varied between 1.3 and 2.5%. Rut depths measured after construction in the middle lane, left wheel path averaged 12 mm; in the middle lane, right wheel path the average rut was 1 mm deep.

3.2 SHOT BLASTING

Following the grinding, high velocity shot blasting was done to clean debris left from the milling process; to provide a uniform wearing surface; to increase the skid resistance, and to remove any micro-fractured material. The shot blasting may also improve the pavement drainage by creating micro-sized points that break the hydraulic bond of water *(Lindquist 1996)*. The shot blasting equipment was manufactured by Blast-Trac, now owned by US Filter, headquartered in Newnan, GA. The 2-48D electric machine blasts a 1.22 m wide pattern and weighs 2,702 kg. It uses a separate dust collector and recycling system to handle debris and steel shot recycling. The total length of both machine and dust separator is 6.7 m.

Shot blasting did not start until the second night of construction. The shot blasting had to be done when the pavement was dry or the vacuum would clog. The shot blaster included a magnet that collected the shot for recirculation. Unlike the grinding, the entire width of the freeway was shot blasted. Once grinding started the shot blasting machine was shut down because of the wet pavement from the milling process. On one night, when the pavement was damp, a torch was used to evaporate the pavement moisture ahead of the shotblaster.

The shot blasting equipment is reported to operate at about 9 m/min over a 1.22 m wide path. Measured production rates ranged from 7.2 to 7.9 m/min. Approximately 0.8 to 1.6 mm depth of concrete was removed during the shot blasting.

3.3 CONSTRUCTION NOISE LEVELS

Construction noise levels were measured for 20-minute periods during the milling portion of the project by a private consultant. The measurement location was 3.65 m west of the outside shoulder, near the southbound truck lane. The two inside southbound travel lanes were closed to traffic at the time of measurements. Noise sources associated with the milling operation include the rotomill, haul trucks, and street sweepers *(Minor 1998).*

Ambient noise levels were measured from below 60 dBA to 84 dBA. Maximum noise levels for the milling machine were measured at 95 dBA at 7.6 m from the noise meter. The maximum levels were achieved just as the rotomill passed the measurement location. It was clear from the data that the rear of the rotomill was the primary noise source. Other sources of noise, including the haul trucks and the street sweeper, were not noticeable over the noise of the rotomill.

Using this type of construction activity near a residential area would depend on many factors, including:

- The existing ambient noise levels. It is desirable to keep the construction noise levels within two to five dBA of the existing ambient levels. This may not be an issue near a relatively noisy major highway.

- The distance from the source to the residential area. The noise level decreases by 6 dBA with each doubling of the distance from the source. The area of influence for this operation along major highways is projected to be about 60 to 90 m from the construction activities. This is the distance where construction noise would be about equal to the ambient noise for most highways.

- Time of operation. Milling during evening and nighttime hours would have the most negative effect, like other highway construction activities requiring heavy equipment, and a noise control variance may be required for use near residential areas.

3.4 AIR QUALITY

The Oregon Department of Environmental Quality (DEQ) established two monitoring sites to collect air quality data. The "north" site was a few hundred meters from the north end of the project and the "south" site was a few hundred meters from the south end. Both sites were in the median strip about 3 m from the edge of the inside shoulder. The wind flow was generally from the west to east; however, no wind direction or wind speed sensors were installed in the area.

Each site had a fine particulate sampler and a coarse "fallout" bucket. The filter on each sampler was changed each day; the buckets were not changed, but exposed for both days *(Smith 1999)*.

3.4.1 Fine Particulate Samples (PM2.5)

Samples were collected during the night from 7:00 pm to 7:00 am. The fine particulate materials captured ranged from 10 to 23 $\mu g/m^3$. The standard for PM2.5 for a 24-hour average is 65 $\mu g/m^3$. The measured particulate levels were well under the standard.

3.4.2 Coarse Fallout

The standard for particulate fallout buckets (PFOs) is 5 g/m^3/month. The buckets were only exposed for a couple of days. The impact of the two days is in the 3 to 4 g/m^3/month range which is close to the standard. If work continued on the same section of highway for an extended period of time, the PFOs would most likely exceed the standard.

3.4.3 Air Quality Discussion

Fine particulate does not seem to be a problem, but coarse fallout may be, if additional milling passes were made, extending the time period in one area. High PFOs would only become an issue if the milling operation was near a residential area. The technician who picked up the samples (during the day when no work was going on) noted that the traffic was stirring up the dust that was left along the shoulder of the road. DEQ suggested that more or better sweeping and pavement washing all the way to the edge of the shoulder would help keep the dust impacts down.

4.0 POST CONSTRUCTION EVALUATION

To further evaluate the effectiveness of the millabrading system, a maintenance and field survey was performed. In addition, noise, friction and roughness testing was done with data collected before and after construction for comparison. Finally, accident data was reviewed.

4.1 MAINTENANCE ISSUES

Based on discussions with ODOT District Maintenance personnel, the millabraded section appears to be performing adequately. No problems with drainage have been noted. Following construction, there are still ruts in all the wheel paths, however, even with the change in the cross slopes, no drainage problems have been noted.

4.2 POST CONSTRUCTION INSPECTION

The test section was inspected on April 10, 1999. The local maintenance office provided a two-lane closure so that the middle and fast lanes could be inspected. Random rut measurements using a rut bar varied from 10 to 16 mm in the middle lane. Some remaining rut depth was expected based on the project design, however, not to the degree measured. The greater rut depths may have been due to insufficient pre-construction survey data used for the design. Figure 4.1 shows the middle lane pavement appearance looking south.

Figure 4.1: Post Construction Pavement Looking South (4/10/99)

The sawcut joint between the fast and middle lane appeared more spalled than the construction joint between the middle and truck lane. The spalling noted for both longitudinal joints would be classified as low severity as defined by the *SHRP Distress Identification Manual for the Long-Term Pavement Performance Project (SHRP 1993)*, however, it was more apparent than before milling. Figure 4.2 shows the spalling observed between the fast and middle lane sawcut joint at two locations.

Figure 4.2: Low Severity Spalling at Construction Joint (4/10/99)

4.3 CONCRETE CONDITION

Three cores were obtained from the test section to investigate the post construction condition of the PCC pavement. The cores were sent to Erlin, Hime Associates out of Austin, TX for petrographic study.

The results of the study indicated that the top size gravel was 32 mm. Slight microcracking of the aggregates on the surface was detected, however, the cracking was not judged to be significant and did not appear to be compromising to the surface durability. The paste along the abraded top surface was free of microcracking. The report concluded that bonding to surface overlays should be adequate *(Patty 1999)*.

4.4 IN-VEHICLE NOISE LEVELS

The noise measurements shown in Table 4.1 were taken **inside** an automobile traveling in the middle lane through the project. The noise measurements were taken while travelling at 97 km/hr on dry pavement. Measurements were taken with a B&K Model 2221 Sound Level Meter for 30 seconds. The same vehicle make and model was used for the before and after rehabilitation measurements *(Poecker 1998)*.

Additional measurements were taken just south of the project for comparison. The noise levels were taken on a newer continuously reinforced concrete pavement section just south of the project and on a two-month old open-graded asphalt concrete overlay also south of the project. The measurements were taken in the middle lane, for approximately 30 seconds travelling at 97 km/hr. The results are shown in Table 4.2.

Table 4.1: In-Vehicle Noise Measurements

Run Number	Before: Interior Noise Level, Leq/dBA[1]	After: Interior Noise Level, Leq/dBA[1,2]
1	77	74
2	77	72
3	76	73
4	77	70
5	76	73
6	--	74
Average	**77**	**73**

[1] Average traffic conditions.
[2] Noise levels were variable, depending on where the wheels were in the travel lane.

Table 4.2: Miscellaneous In-Vehicle Noise Measurements

Run Number	Pavement Type	Interior Noise Level, Leq/dBA
A	Concrete	69
B	F-Mix Overlay	69
C	F-Mix Overlay	70
D	F-Mix Overlay	70
E	F-Mix Overlay	69

The noise measurements taken inside the car after millabrading indicate that the overall noise levels were slightly less than prior to the pavement rehabilitation. The average measured noise levels inside the car decreased by 4 dBA after the pavement rehabilitation work. Based on observations from inside the car, the decrease in noise levels was readily perceptible within the test section when compared to the pavement noise noted before and after project construction.

A 3 dBA change in noise levels is considered to be perceptible by average human hearing. A 10 dBA change in noise levels is perceived as a doubling (or halving) of noise by average human hearing. The rehabilitated section is not as quiet as the newer concrete section and the new F-mix overlay sections with a difference of 3 dBA. The noted observations agree well with these measurements.

4.5 PAVEMENT FRICTION

All friction testing was done at speeds near 64 km/hr in the left wheel path of all three lanes using a K.J. Law trailer. The data from the tests were converted to standard 64 km/hr friction numbers using correlation equations. Skid testing was performed before the milling and then several times after project completion. One skid test was done after the milling but prior to the shot blasting in the middle lane. The average skid numbers for the three lanes are shown in Figure 4.3.

The November 3, 1998 friction testing includes results for shot blasted sections (fast and slow lanes) and a section with only milling (center lane). The milling increased the skid number from 34 to 39 in the center lane. With the shot blasting, the center lane skid number increased from 39 to 47. Skid numbers, however, have continued to decline, returning to near the preconstruction skid numbers.

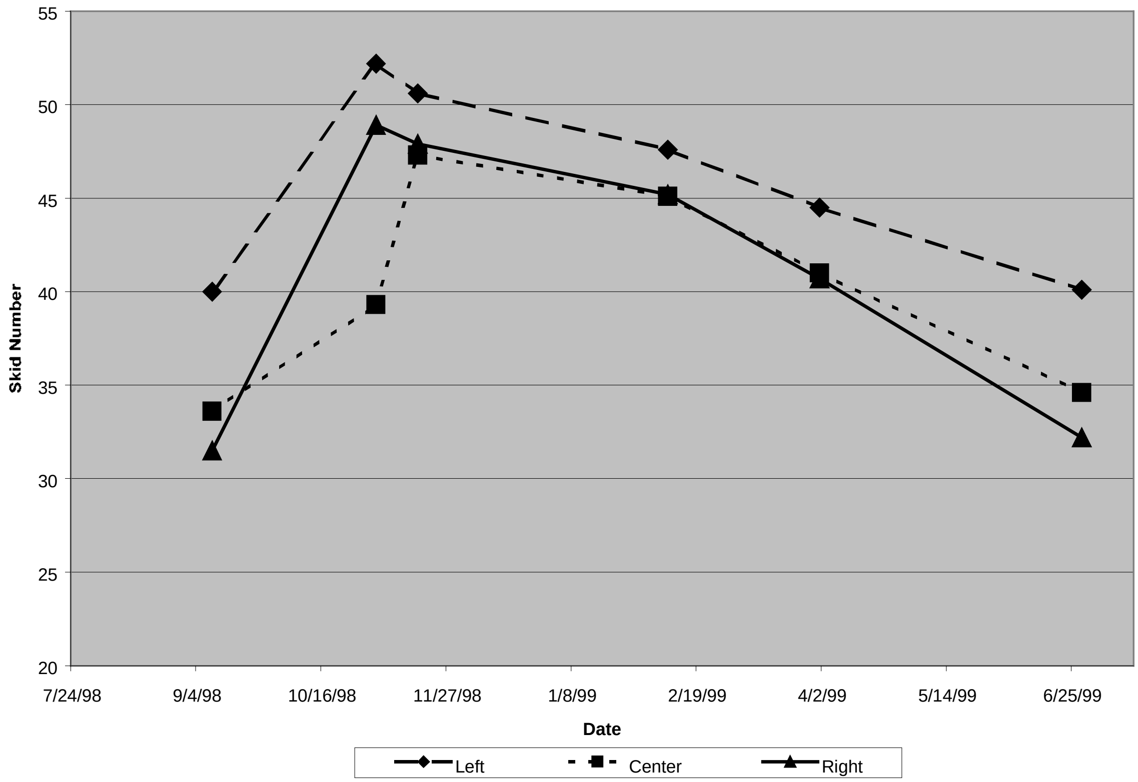


Figure 4.3: Friction Testing Results

4.6 PAVEMENT RIDE

The roughness, or ride, of the pavement was measured with the ODOT Pavement Service's van equipped with a South Dakota profilometer. The South Dakota profilometer readings are used to calculate the International Roughness Index (IRI) representing the smoothness of the road. Readings were taken before and after construction, as shown in Table 4.3.

Table 4.3: IRI Values (in/mile)

	Left Lane (Fast Lane)		**Center Lane**		**Right Lane (Truck Lane)**	
	Left Wheel Path	Right Wheel Path	Left Wheel Path	Right Wheel Path	Left Wheel Path	Right Wheel Path
9/13/98	99	82	109	83	107	117
12/9/98	100	90	99	64	108	130

Note: To convert from in/mile to mm/km multiply by 15.78.

The IRI measurements are very sensitive to tire placement when driving through the section. Slight differences are to be expected. The center lane in the right wheel path, however, appears to be smoother than the original section with a decrease in the IRI of 19 in/mile.

4.7 ACCIDENT HISTORY

Accident data was obtained from ODOT's Transportation Data Section. Accident reports were obtained between MP 286 and 288 to get an idea of the types of accidents to expect in this area. The majority of accidents in the last three years were caused by rear-ends or sideswipe-overtaking. The majority of accidents also occurred on dry pavement.

Looking at accident reports for just the millabraded test section, there were three accidents in 1997 and none reported in 1998 (prior to construction). Two of the accidents occurred on a dry day where the vehicle was travelling too fast or following too close. The third accident occurred on wet pavement and was attributed to a vehicle following too close. Unfortunately, data beyond November 1998 has not been coded and entered into the database. Comparisons between prior and post construction cannot be made except to say that there were no accidents reported in November 1998 while the section was being constructed.

5.0 COMPARISONS WITH OTHER METHODS

Other PCC rehabilitation alternatives considered by ODOT include diamond grinding and asphalt concrete overlays. Diamond grinding has been used for rut repair on several PCC pavements across the country *(Mack* 1999*)*. For comparison, a recent project constructed by Washington Department of Transportation (WsDOT) is described. ODOT's most recent PCC rehabilitation strategy has been to overlay the pavement with asphalt concrete. The overlay projects most recently constructed near the test project are discussed.

5.1 DIAMOND GRINDING

Performance of diamond grinding of PCC pavements was recently summarized in *a Roads and Bridges* article *(Mack 1999)*. The study included a review of data from more than 180 sites. The study showed that diamond grinding is an effective means to extend pavement service life. The process can be used to address roughness and wheelpath rutting, among other things. It also indicated that the level of smoothness obtained is equal or better than that of a new pavement or overlay. In addition, no evidence of deleterious effects of diamond grinding was observed at any of the field sites.

On jointed concrete pavement, the study found that diamond grinding may extend the pavement life between 8-20 million equivalent single axle loads (ESALs), depending on the climate. Cracking analysis indicated that a pavement slab could be reground up to three to four times without compromising fatigue life.

WsDOT recently removed the ruts in PCC pavement on I-5 at Tukwila to Lucile Street (#5372) *(Brown 1999)*. The project included diamond grinding followed by shot blasting. Because the diamond grinding created a polished finish which created glare, the Skidabrader (large shot blaster) was used to dull the surface. In addition, the shot blasting reduced the channelization (grooves), reducing the tendency for vehicles to track. At one point, the contractor attempted to remove the middle hump between the wheel ruts with a rotomill. The rotomill increased the amount of spalling and the process was stopped after 60 m. Reportedly, the rotomill included a standard drum (versus a drum with more closely spaced teeth) that may have contributed to the spalling. Production rates and costs are presented in Table 5.1.

5.2 ASPHALT CONCRETE OVERLAY

ODOT recently constructed 35 km of AC overlay on the PCC sections of I-5. Both northbound and southbound sections were overlaid across three lanes. Pavement preparation included filling in the ruts with a fine asphalt concrete mix (12.5 mm, max size aggregate) in the middle lane only. The entire lane was then covered with a tack coat. The overlay consisted of 50 mm of asphalt concrete, open graded mix (25 mm max. size aggregate). Production rates and costs averaged from the recent two projects (Baldock - Woodburn #C12119, Woodburn - SPTC #C12101) are shown in Table 5.1.

Table 5.1: Rehabilitation Methods Comparison

Alternative	Production Rates	Costs[3]	Considerations
Millabrading	700 to 880 m^2/hr (milling only) 530 to 580 m^2/hr (shot blasting only)	\$6.90/ m^2 (milling) *(See note 4)* \$2.30/ m^2 (shot blasting)	• Extends service life of existing pavement; requires no virgin materials. • Milling can be performed during fewer weather limitations than AC overlays. • Can be feathered into adjacent pavement structures. • Can be performed selectively on sections. • No structure clearance issues. • Reduces structure of section. • May increase spalling at joints. • Suitable for pavements with adequate structural support and re-bar coverage.
Diamond Grinding[1]	40 to 50 m^2/hr (grinding only)	\$10.93/ m^2 (grinding) \$1.73/ m^2 (shot blasting)	• Slow process. • Extends service life of existing pavement by restoring the surface, however, reduces structural capacity of CRC pavements. • Requires no virgin materials. • May result in polished aggregate and corduroy surface, which may still require shot blasting or similar. The WsDOT project specified the use of the Skidabrader. • Can be performed during fewer weather limitations than AC overlays. • Produces less spalling than rotomilling. • Can be feathered into adjacent pavement structures. • Can be performed selectively on sections. • Improves skid resistance. • Suitable for pavements with adequate structural support and re-bar coverage.
Asphalt Concrete Overlay[2]	4000 m^2/hr	\$2.80/ m^2	• Least impact to traffic as process is relatively quick. • Provides splash and spray resistance. • May require raising of structures to allow for truck clearance. • Increases structural capacity of section. • More effort required to match into ramps and bridges. • Requires full-width construction (including shoulders).

[1] Based on data collected by Washington DOT on I-5 project constructed in 1998 *(Brown 1999).* Production rates were about 90 m^2/hr for the Delta Park-Marquam Bridge Section project.
[2] Based on data collected on projects constructed on I-5 earlier in 1998: Baldock - Woodburn; Woodburn - SPTC.
[3] Traffic control costs not included.
[4] Shot Surfacing Incorporated estimates that the cost for milling could be reduced to \$3.50 to \$4.00/m^2 for a large quantity project.

5.3 COMPARISON DISCUSSION

To compare the options, along with unit costs, Table 5.1 presents the production rates and other issues necessary for consideration when selecting a rehabilitation alternative. Because this was a test project, direct cost comparisons between millabrading, diamond grinding, and asphalt concrete overlays are shown for documentation only. Comparisons between production rates, however, can be made since they would directly affect user costs/traffic impacts. It would take five rotomills to equal the production of the paving done on the large scale I-5 projects done in 1998. For areas with bridge clearance issues the user costs/traffic impacts associated with slower production may be less of a factor.

A complete comparison should include a life cycle cost analysis. Without knowing how long the millabrading treatment lasts, a life cycle cost analysis is not possible. It is known that reducing the thickness of the pavement slab will increase the pavement stresses, resulting in a reduced service life. As noted in the diamond grinding study *(Mack 1999)*, some pavements can be diamond-ground several times. This should hold true for millabrading assuming there is adequate structural capacity. A limiting factor in Oregon would be the amount of reinforcing bar cover. Subsequent milling on the continuously reinforced concrete pavement could actually expose the reinforcing steel which would require extensive concrete repair and possibly reduce the pavement section's fatigue life.

Consideration should be given to the potential impacts of spalling associated with rotomilling. A more open joint allows moisture into the base and subgrade materials, which could reduce the pavement performance. In addition, spalled joints could create a hazard for motorcycle traffic. Also, if the pavement will be overlaid in the future, the joint would need to be treated prior to overlaying to provide adequate support to prevent reflective cracking.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The following conclusions were reached following the eight-month evaluation of the millabraded section.

Like any construction requiring heavy equipment, issues like noise and air quality need to be considered. Construction noise levels should be evaluated if the grinding is to take place near a residential area. The noise impacts will be a function of ambient noise levels, the distance from the source to the residential area, and the time of operation. Air quality, particularly coarse particulate fallout may be a problem if the rotomilling is done for an extended period in one area.

A post construction inspection measured random rut depths of 10 to 16 mm in the middle lane. Some rutting was expected, however, not to the degree measured. Insufficient survey data may have impacted the design and subsequent outcome. If the millabrading had been performed full-width, it is expected that the ruts would have been eliminated.

Also noted during the post construction inspection, the longitudinal joints appeared spalled. A petrographic analysis indicated that there is no micro-cracking that may be detrimental to the durability of the section. Accident data for comparison between the before and after conditions is not currently available, therefore, assessments of the traffic impacts attributable to the broken slope in the middle lane are currently unknown. District maintenance staff report no problems with the section.

Field test results indicate that in-vehicle noise levels are noticeably lower after construction. Because some of the pavement ruts still remain, the reduction in noise is dependent on where the tires hit in the lane. Pavement friction values increased following the grinding and additionally after the shot blasting. Friction values, however, have continued to decrease for the last eight months following construction. The pavement ride or roughness appears to be slightly reduced following the millabrading process. Again, since some rutting still remains, the IRI reductions are dependent on where the roughness is measured.

6.2 RECOMMENDATIONS

The millabrading system tested on I-5 should be considered among the rehabilitation options available for continuously reinforced PCC pavements with adequate structural support and re-bar cover. Although the constructed test section did not fully remove the pavement ruts, if the entire width of the pavement could have been milled, the ruts could have been removed.

Future projects should incorporate the following items:

- The need for the shot blasting should be further investigated. Shot blasting is primarily necessary for cleaning the surface, reducing the micro-cracking, and increasing skid resistance. It is not known whether additional sweeping could clean the surface or if micro-cracking is a significant issue. The benefits of improved skid resistance from the shot blasting appear to be short term.

- Future projects should include a thorough set of cross sections to insure that rut depths can be effectively reduced. This is critical for a middle lane treatment similar to the test.

- Crack filling using proprietary filler or other slurry type material should be investigated to reduce spalling of longitudinal joints.

- Millabrading specifications need to specify the machine weight and tooth spacing as shown in the test project's Special Provisions. Both factors are critical to the project outcome. Future projects should also specify a production rate, shown to minimize potential aggregate popout and spalling.

- Future grinding projects should include an investigation and ultimately the development of an end product specification. Items to monitor would be rut depth reduction, pavement smoothness, skid resistance and spalling amount. The specification could also require the contractor to demonstrate the ability to achieve the desired results prior to full-scale operations.

7.0 REFERENCES

Brown, Doug. Phone conversation. Washington Department of Transportation, May 6, 1999.

Halton, Tony. Fax Transmittal. Shot Surfacing Incorporated, March 2, 1999.

Lindquist, Eric. *Demonstration Job Report, Hyak Vicinity*. Shot Surfacing Incorporated, August 29, 1996.

Mack, James W. *Diamond-grade pavements*. Roads & Bridges, April 1999.

Minor, Michael. *Pavement Grinding Noise Level Measurements*. Michael Minor and Associates, Technical Memorandum, December 29, 1998.

Oregon Department of Transportation. *1998 Pavement Condition Report*. Pavement Management Group, October 1998.

Patty, Tom S. *Petrographic Studies of Interstate Highway 5 (I-5) Pavement Cores for Oregon Department of Transportation.* Erlin, Hime Associates Construction Materials Consultants, Technical Memorandum, February 8, 1999.

Pierce, Linda. Phone conversation. Washington Department of Transportation, May 14, 1999.

Poecker, Rick. *Noise Measurements for Concrete Pavement Rehabilitation.* ODOT Environmental Services, Technical Memorandum, November 19, 1998.

Smith, Jeff. E-mail Transmittal. Oregon Department of Environmental Quality, March 31, 1999.

Strategic Highway Research Program, National Research Council. *Distress Identification Manual for the Long-Term Pavement Performance Project*. SHRP-P-338, 1993.

Villalpando, Jose. *Delta Park-Marquam Bridge Section Narrative Report.* Oregon Department of Transportation, February 4, 1991.

APPENDIX

SPECIFICATIONS

SECTION 00622 – PCC PAVEMENT MILLING

00622.00 Scope – This work consists of rehabilitation of existing reinforced concrete pavement by a two part process to remove ruts and texture surface.

Rehabilitation of existing surfacing will be by millabrading (micro milling) rutted center travel lane and shot blasting (texturing) entire roadway width as detailed, specified and directed.

The work will be done as a developmental project with a test section of approximately 0.80 km in length.

Equipment

00622.20 Equipment – Provide self propelled milling and shot blasting machines as follows:

- Provide a pavement profiling machine with an operating weight of 356 KN, equipped with a special cutting head utilizing a 4.5 mm tooth spacing and pattern tolerance of 3.2 mm depth across the surface.
- Provide a high velocity shot blast machine with a 1.22 m wide blast pattern to texture the surface. The machinery shall include a self-contained dust collection system that recycles the steel abrasive media and complies with EPA standards for clean air. Both units, blast machine and dust separator, shall be electric powered.

Construction

00622.40 Millabrading Test Section:

Perform profile milling of the continuously reinforced concrete pavement rutted surface to the profile established in the typical section. Cross slope will be maintained at 1% minimum and 3% maximum.

The profile mill shall maintain a milling pattern that shall be uniform and that broken teeth will be replaced as needed on the 4.5 mm spacing drum. Milling shall be performed with a minimum amount of pullouts and spalling. Any abrupt changes in elevation across the pavement surface caused by the milling process shall be corrected at the Contractor'' expense to the satisfaction of the Engineer.

Following the milling process, high velocity shot blasting will uniformly texture the entire width of the roadway to increase skid resistance, and also remove any micro-fractured material.

Measurement

00622.80 General – Quantity of materials to be removed by milling operation and the area to be shot blasted, will be determined by measuring the actual surface areas to the nearest 50 mm and computed to the nearest 0.1 m^2.

Payment

00622.90 General – Payment for performing all work required under this Section to remove and dispose of the existing pavement milled and shot blasted as specified, including replacement of cutting teeth, will be made at the contract price per m^2 for under the items "PCC Milling" and/or "PCC Pavement Shot Blasting" as applicable.

Payment will be payment in full for furnishing all equipment, tools, labor and incidentals necessary to complete the work as specified.