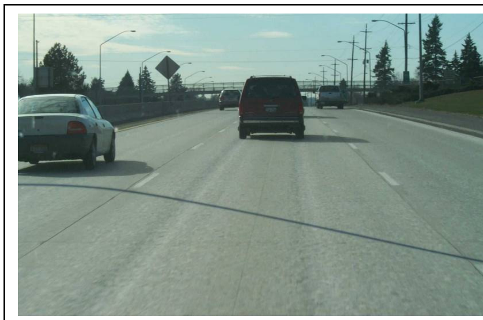
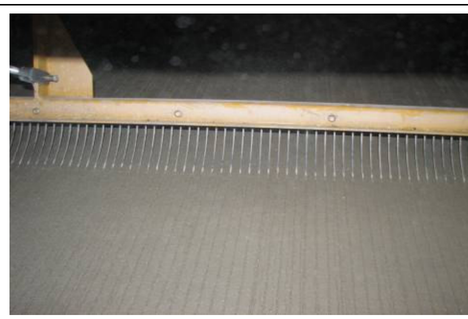
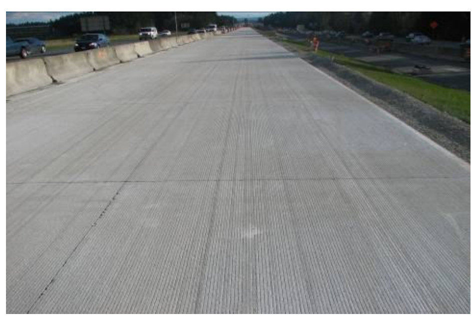
Experimental Feature Report

Post Construction Report
Experimental Features WA 05-05

Performance of a Portland Cement Concrete Pavement With Longitudinal Tining, Transverse Tining, and Carpet Drag Finish

Contract 6883
I-5
Pierce Co. Line to Tukwila I/C – HOV – Stage 4
MP 139.06 to 144.75



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16. ABSTRACT

This report describes the construction of a portland cement concrete pavement built with three finishing methods; carpet drag, longitudinal tining, and transverse tining. The three finishing methods will be compared for their ability to resist the wear from studded tires. Ride and friction resistance will also be monitored and reported over the five year evaluation period.

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Introduction

Washington State Department of Transportation's (WSDOT) portland cement concrete pavement (PCCP) construction program has been relatively small since the completion of the Interstate system in the 1960's and early 1970's. Many of these pavements are now reaching the end of their useful lives and are being programmed for reconstruction. It is essential that the best possible materials and construction practices be used in order to ensure pavement service lives of 40 years or longer. This has led to the development of a number of experimental features that have been incorporated into PCCP construction projects to evaluate various innovative materials or construction practices that may provide better performance, especially pavements that are more resistant to studded tire wear. Washington is one of the three states in the western part of the United States that sees a lot of studded tire usage during the winter months, the other two states being Oregon and Alaska.

This report describes the construction and post-construction testing of a PCC pavement with a longitudinal tined finishing. This project, Contract 6883, Pierce County Line to Tukwila I/C – HOV – Stage 4, also included sections of transverse tined finish to serve as a control section for the longitudinal tined finish. The remainder of the project received a carpet drag finish. This is the second of three projects that have incorporated a carpet drag finish as an alternative to transverse tining, the standard finishing method for WSDOT. The other two projects are Contract 6757, I-5, Federal Way to South 317th Street HOV Direct Access which abuts this project and the second project is Contract 6620, I-90, Argonne Road to Sullivan Road, which is located in Spokane, Washington. Details on the construction and post-construction testing of these projects can be found on the WSDOT web site[1] under the titles "Performance of a PCCP with Carpet Drag Finish" and "Studded Tire Wear Resistance of PCC Pavements".

[1] http://www.wsdot.wa.gov/biz/mats/pavement/pavementresearch.htm#concrete

Background

The primary objective of this experimental feature is to evaluate how a new PCC pavement with a longitudinal tined finish will resist the wear from studded tires. The wear measured on PCC pavements in the state of Washington is primarily due to allowing studded tires to be used between November 1 and March 31. The damage from studded tires results in gradual dishing of the wheel paths to actual visible ruts in the wheel paths. In the case of the standard WSDOT finishing method, transverse tining, this loss of material results in no visible trace of the tining after as little as three years of traffic. Figure 1 shows a concrete pavement that was constructed in 1995 on state route (SR) 395 just south of Interstate 90 (Ritzville vicinity). At the time of this photo, this pavement had been in service for seven years (photo taken in 2003). The average annual daily traffic on this route is approximately 6,800 vehicles. It can be seen that the tining in the wheel paths has been completely worn away due to studded tires (note that the tining is still visible at the pavement edges).

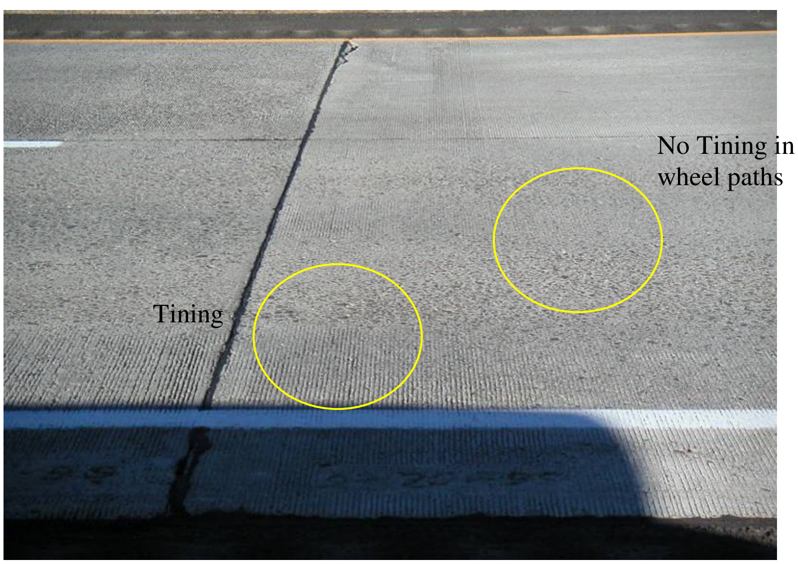

Figure 1. Concrete pavement on SR-395 south of Interstate 90 interchange.

In contrast, Figure 2 shows a 13 year old concrete pavement located on Interstate 45 in Houston, Texas. Note the clear pattern of the tine marks across the entire width of the pavement lane. The average daily traffic count on this section of interstate is 178,000 vehicles per day. Though the state of Texas allows studded tires, in reality the climate in Texas does not typically warrant the use of them. The damaging effects of studded tires is clearly observable in these two examples which is made even more dramatic when considering that the Texas pavement has received more than 26 times the daily traffic volume (6,800 versus 178,000) and has been in place for almost twice the number of years (seven years versus 13 years) as the pavement on SR 395.

Figure 2. Concrete pavement on Interstate 45 in Houston, Texas after thirteen years of traffic.

An even more dramatic example of studded tire wear is shown in Figure 3. The wear, in this case, has formed ½ inch deep ruts in the PCC pavement. This type of rutting is especially prevalent in the Spokane area, which is reported to have the highest use of studded tires in the entire state.

Figure 3. Wear due to studded tires on a PCC pavement (I-90 vicinity of Spokane).

A series of experimental features are underway that address various strategies to mitigate this type of wear (Table 1 – this project is noted in bold type). These include the use of combined aggregate gradation, higher strength mix designs, additives that produce a harder cement paste and various finishing methods such as carpet drag and then on this project longitudinal tining. The construction project located just north of this one included the use of the carpet drag finish on the HOV lane and this project used the carpet drag finish on the southbound HOV lane as well. The plan is to build a portion of a project in eastern Washington using the longitudinal tining finish to provide a section in a heavy studded tire use region to compare to this installation.

Table 1. Experimental features on mitigation of studded tire wear in PCCP.		
Exp. Feature Number	**Experimental Feature Title**	**Location**
01-02	Combined Aggregate Gradation for PCCP	I-90, Sprague Ave I/C Phase III, C6947
03-02	Ultra-Thin Whitetopping/Thin Whitetopping	I-90, Sullivan Road to Idaho State Line, C6582
03-04	PCCP Features (Carpet Drag, Flexural Strength, and Surface Smoothness)	I-90, Argonne Road to Sullivan Road, C6620
04-01	Use of Hard-Cem in Concrete Pavements	I-90, Argonne Road to Sullivan Road, C6620
05-02	PCCP Features (Carpet Drag and Noise Mitigation)	I-5, Federal Way to S. 317th Street HOV Direct Access, C6757
05-04	PCCP with Higher Slag and Cement Content	I-90, Argonne Road to Sullivan Road, C6620
05-05	**PCCP Features (Carpet Drag and Noise Mitigation)**	**I-5, Pierce Co. Line to Tukwila I/C - Stage 4, C6883**

This project is also a site for monitoring tire/pavement noise as WSDOT investigates the feasibility of using different types of pavement as mitigation strategies to reduce roadway noise. Longitudinal tining finish has been shown to be “quieter” than transverse tining. This section will be monitored beginning in the fall of 2006.

FRICTION REQUIREMENTS AND NOISE MITIGATION

The Federal Highway Administration technical advisory T 5040.36, entitled "Surface Texture for Asphalt and Concrete Pavements," provides guidance to states regarding pavement types or mitigation strategies that have been successful in providing pavements with acceptable friction resistance characteristics. This advisory can be found at the following website: http://www.fhwa.dot.gov/legsregs/directives/techadvs/t504036.htm

The advisory lists tining, exposed aggregate surface, broom or artificial turf drag, diamond grooving, and diamond grinding as treatments that can yield adequate wet weather friction characteristics for concrete pavements. The choice of artificial turf drag comes with the additional requirement that states must provide proof that the technique will provide adequate wet weather friction resistance over the long-term. The advisory does not define "long-term," but because it is a safety issue one might presume that it is an extended period of time such as 20-30 years. This experimental feature will collect information on the long-term performance of artificial turf drag as compared to transverse tining with respect to friction.

Currently there is a national interest in the possibility that certain hot mix asphalt pavement types or certain concrete finishing techniques could be used as substitutes for noise walls or used in conjunction with walls as an overall acceptable noise reduction strategy. The use of aggressive transverse tining has been cited as one of the causes of higher noise levels by some states. As a result, FHWA is allowing states to experiment with different finishing techniques as a means of providing sufficient supporting data to allow their use as a noise mitigation strategy. Again, long-term performance is an issue that must be resolved through documentation of noise and pavement performance. Until such time as a strategy or methodology has proved to provide a quieter pavement over time, FHWA will restrict the use of pavement type or finishing method as a noise abatement measure. FHWA has developed guidelines for qualification of pavement type as an acceptable noise mitigation strategy under a program called "Quiet Pavement Pilot Program" (QPPP), see FHWA web site[2] for more details.

[2] http://www.fhwa.dot.gov/environment/noise/qpppmem.htm

It is not currently WSDOT's plan to file a QPPP plan, but it is interested in collecting data on different pavement types and finishing methods that could result in a reduction of noise for communities in the state. The Arizona Department of Transportation (ADOT) is leading efforts to qualify asphalt-rubber friction courses as noise mitigation strategies and is the only state to have filed a QPPP plan. It is WSDOT's intent to work closely with ADOT and the states involved in the State Pavement Technology Consortium (SPTC) to gain from their experience. The SPTC is comprised of four states, California, Minnesota, Texas, and Washington. In addition, WSDOT intends to closely monitor California Department of Transportation (Caltrans) who has embarked on a multi-year, multi-million dollar study on mitigation of pavement noise.

Tire/pavement noise measurement at WSDOT were begun in the fall of 2006 using an On-Board Sound Intensity (OBSI) method that uses two microphones mounted near a tire on a sedan to measure sound intensity levels. A report on the tire/pavement noise measurements for this project will be included in a separate report dealing only with this issue at some later date.

Project Description

The project is located on I-5 between Tacoma and Federal Way, Washington. Construction consisted of the building of north and southbound HOV lanes between mileposts (MP) 139.06 and 144.75 for a total of 11.38 lane miles. The average daily traffic on this section is 85,317 with 8.7% trucks. A vicinity map showing the project limits is provided in Figure 4.

Figure 4. Vicinity map of Contract 6883, I-5, Pierce Co. Line to Tukwila I/C – HOV – Stage 4.

The prime contractor on the project was Icon Materials out of Tukwila, Washington and the subcontractor for paving was Salinas Construction from Everett, Washington. The concrete supplier was Miles Sand & Gravel out of Auburn, Washington. The WSDOT project engineer was Stanley Eng from the Northwest Region. A total of 41,473 cubic yards of portland cement concrete was planned to be placed.

Experimental Sections

A change order was issued on the contract (Appendix A) to insert the longitudinal and carpet drag finish into the project. The change order stipulated that the HOV lanes would be finished with carpet drag from the southern end of the project to Bridge 5/504W. The longitudinal tining would be applied from Bridge 5/504W to within 300 feet of the end of the project in each direction. The remaining 300 feet of the lane in each direction would receive a transverse tined finish. The result of following the change order would be 2,221 feet of longitudinal tined pavement in the southbound HOV lane and 3,292 feet in the northbound HOV lane.

The specifications for the longitudinal tining required that the spring steel tines be rectangular in cross section with a width between 3/32 and 1/8 inch placed on 1 inch centers. The grooves formed by the tines are to be parallel with centerline and approximately 3/16 inch in depth but can vary between 1/16 inch and 5/16 inch. The transverse tining followed the WSDOT Standard Specifications which calls for grooves perpendicular to centerline and 1/8 to 3/16 inch in depth randomly spaced from ½ inch to 1 ¼ inch apart. The carpet drag finish is to be produced with a single piece of artificial turf dragged parallel with centerline. The depth of texture produced by the carpet dragging is to be a minimum of 1.0 millimeters as tested using ASTM E965 "Measuring Pavement Micro Texture Depth Using a Volumetric Technique", more commonly know as the sand patch test.

The plan for the longitudinal tining was not followed completely by the Contractor. Longitudinal tining was applied to the northbound HOV lane only and extended a total of 3,018 feet. The longitudinal tining was not applied to the HOV lane in the southbound direction. The 300 feet of transverse tining on the northern ends of each HOV lane was applied and the remainder of the PCCP on the project received a carpet drag finish (see Table 2).

Table 2. Planned and actual constructed lengths of the finishing methods.

Texture Type	Planned (feet)		Actual (feet)	
Direction	**NB**	**SB**	**NB**	**SB**
Carpet Drag	19,543	19,548	19,817	21,426
Longitudinal	3,292	1,878	3,018	0
Transverse	300	300	300	300

Mix Designs

The mix design used for the pavement was a standard WSDOT 650 psi flexural strength mix. A combined aggregate gradation was used from pit site B-345. Table 3 shows details of the mix design including the sources, types, quantities and specific gravities for the cement, slag, and aggregates in addition to the source, type, and quantities of the water reducer and air entrainment. The 6-sack mix had slag cement substituted for 25% of the Type I-II cement and a water/cementitious proportioning ratio of 0.41.

Table 3. Mix design 15700AS with 650 psi flexural strength.

Item	Source	Type	Lbs/cy	Specific Gravity
Cement	Lafarge	I-II	423	3.15
Slag	Lafarge	I	141	2.83
Agg. Source 1	B-345	Class 2	1,150	2.65
Agg. Source 2	B-345	1-½"	490	2.70
Agg. Source 3	B-345	3/8"	560	2.69
Agg. Source 4	B-345	¾"	1,050	2.70
Water			233	1.00
W/C Ratio			0.41	
Water Reducer	Degussa	Polyheed 997	23 oz/cy	
Air Entrainment	Degussa	MB-AE 90	5-20 oz/cy	

Paving

Paving on the contract occurred over a four month period staring on April 3, 2006 and ending on July 26, 2006. The Contractor used a Gomaco GHP 2800 paving machine and the concrete was delivered to the project using dump trucks. Dowel bars consisting of stainless steel tubes with epoxy bar inserts were set in cages every 15 feet to provide load transfer at the transverse joints. Per WSDOT Standard Specifications, epoxy coated tie bars were used at the longitudinal joints. A Gomaco finishing and curing machine followed the paver to produce the needed texture and to apply the curing compound. The construction process followed standard WSDOT practice except for the longitudinal tining. Figures 5 through 7 show the longitudinal tining process and views of the finished pavement surface on the northbound HOV lane.

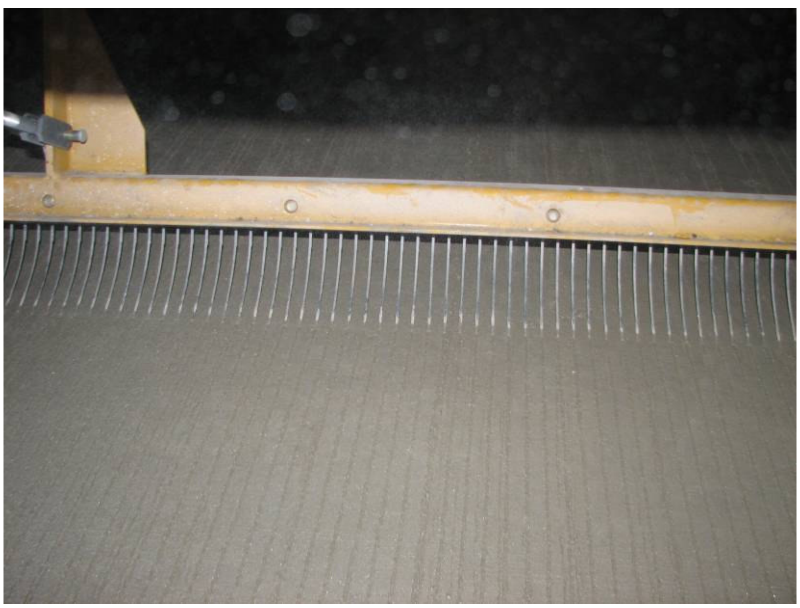

Figure 5. Close-up of the longitudinal tining operation. May 2006.

Figure 6. Close-up view of the pavement with longitudinal tining. May 2006.

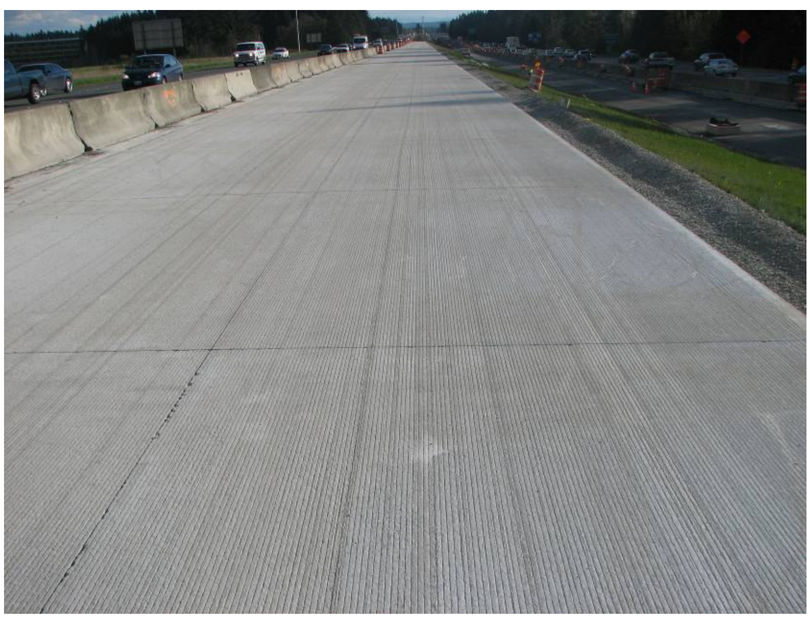

Figure 7. Longitudinal tining in the northbound HOV lane. May 2006.

Test Section Layout

The locations of the carpet drag and longitudinal and transverse tined sections are shown in Figure 8.

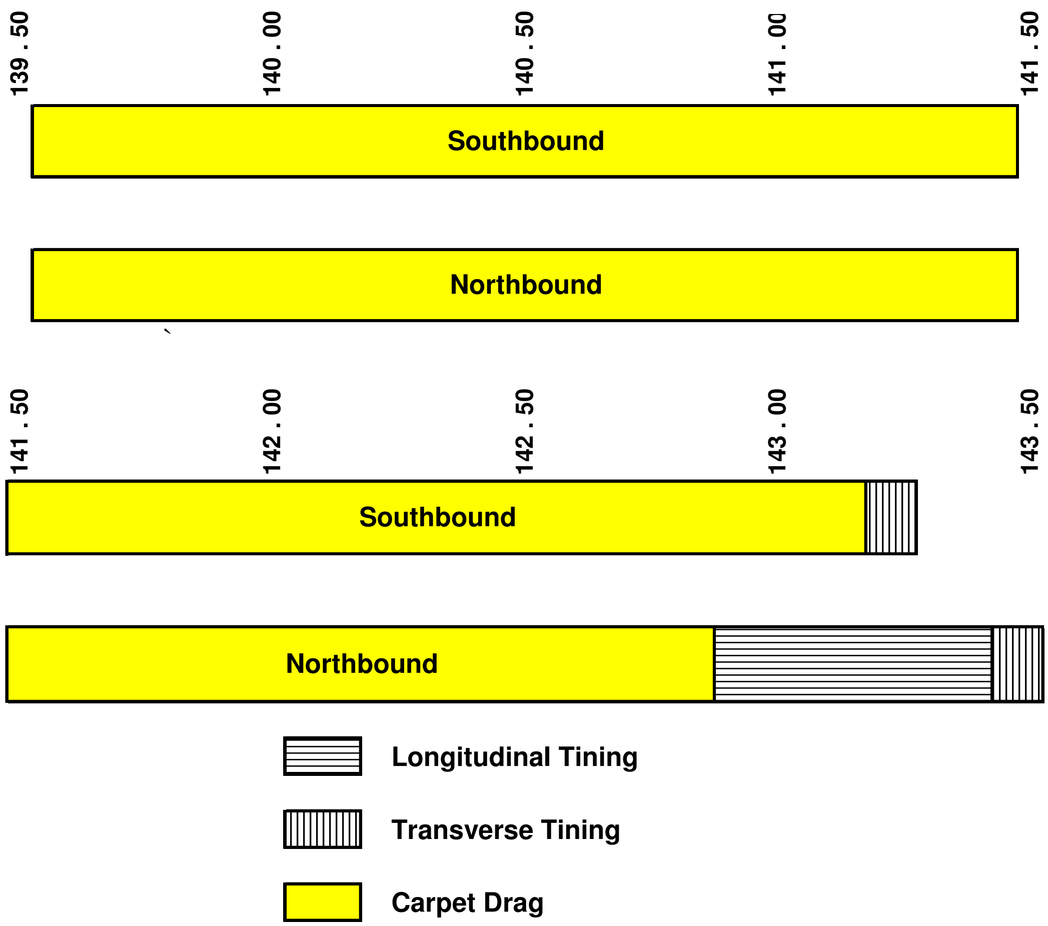

Figure 8. Location of the longitudinal tining, transverse tining and carpet drag sections.

Construction Test Results

The construction acceptance testing of interest to this study was the flexural strength of the hardened concrete. A summary of the cylinder breaks is shown in Table 4 and the complete listing of all the data is contained in Appendix B. The 650 psi flexural strength requirement was easily met by the Contractor with an average flexural strength of 805 psi.

Table 4. Summary of compressive strength results for mix design 15700AS.

	Compressive Strength (psi)	Flexural Strength (psi)
Average	5,190	805
Range	4,020 – 6,630	709 - 910

It is interesting to note that the average flexural strength for this project is about 100 psi higher than the average flexural strength for the adjacent project to the north that was also a standard 650 psi flexural strength design. The average for that project, Federal Way to S. 317th Street HOV Direct Access, was 702 psi as compared to this project's 805 psi average. The Federal Way project used a 6 ½ sack mix of Type I-II cement and this project used a 6 sack mix with slag cement substituting for 25% of the Type I-II cement.

Post Construction Testing

Texture

Sand patch tests were conducted on the finished concrete to measure the depth of texture using ASTM E-965, Measuring Pavement Microtexture Depth Using a Volumetric Technique. The average depth of texture from the sand patch testing was 0.96 mm. A total of 96 locations were tested and 57 (59%) of the tests failed to make the 1.00 mm target specified in the contract Change Order which is included as Appendix A. The northbound and southbound average texture depths were 1.00 and 0.92, respectively. The measurements generally improved as the job progressed. The results are shown in Table 5 which lists the measurements in paving date order. Failing tests are marked with an asterisk. The northbound lane is the LE stations and the southbound the LW stations.

Table 5. Sand patch test results.

Date Paved	Station	Offset (ft)	Ave. Depth (mm)	Date Paved	Station	Offset (ft)	Ave. Depth (mm)
4/3/06	LE505+10		1.65	4/18/06	LW520+67		1.13
4/3/06	LE510+60		0.92*	4/18/06	LW519+30		1.25
4/3/06	LE516+62		0.81*	4/18/06	LW513+80		1.35
4/3/06	LE516+95		0.94*	4/18/06	LW512+00	5	1.45
4/3/06	LE521+59		0.47*	4/19/06	LE505+00	4	1.66
4/3/06	LE522+40		0.61*	4/19/06	LE515+00	6	1.53
4/3/06	LE523+40		0.50*	4/20/06	LE522+00	7.5	0.60*
4/3/06	LE525+40		0.59*	4/20/06	LE522+00	6	0.56*
4/3/06	LE526+40		0.42*	4/20/06	LE530+00	6	0.81*
4/3/06	LE527+60		0.75*	4/24/06	LE535+00	6	1.23
4/3/06	LE528+60		0.69*	5/1/05	LE370+00	4	0.75*
4/3/06	LE529+60		0.80*	5/1/05	LE375+00	4	1.22
4/3/06	LE530+50		0.51*	5/1/05	LE380+00	4	1.28
4/3/06	LE531+50		0.72*	5/2/06	LE390+00	4	0.72*
4/3/06	LE532+50		0.85*	5/2/06	LE390+00	6	0.87*
4/3/06	LE533+15		0.83*	5/11/06	LE395+00	4	1.21
4/3/06	LE538+35		0.63*	5/11/06	LE402+50	4	0.83*
4/3/06	LE539+35		1.17	5/11/06	LE410+00	4	0.99*
4/10/06	LW561+00	6	0.88*	5/15/06	LE420+00	4	1.34
4/10/06	LW555+00	6	0.96*	5/16/06	LE430+00	4	1.51
4/10/06	LW550+00	6	1.09	5/16/06	LE440+00	4	1.36
4/17/06	LW538+00	4	0.31*	5/17/06	LE450+00	4	1.09
4/17/06	LW538+00	5	0.61*	5/17/06	LE460+00	4	1.47
4/17/06	LW533+00	4	0.38*	5/18/06	LE470+00	4	1.64
4/17/06	**LW533+00**	**6**	**0.85***	**5/24/06**	**LE480+00**	**4**	**1.28**

Table 5. (continued) Sand patch test results.							
4/17/06	LW528+00	4	0.76*	5/24/06	LE490+00	4	1.70
4/17/06	LW528+00	5	1.03	5/30/06	LE500+00	4	2.29
4/17/06	LW523+00	4	0.35*	6/19/06	LW490+00	6	0.97*
4/17/06	LW523+00	6	0.46*	6/19/06	LW485+00	6	1.36
4/17/06	LW541+15		0.96*	6/20/06	LW475+00	6	0.89*
4/17/06	LW535+60		0.57*	6/20/06	LW470+00	6	1.23
4/17/06	LW534+60		0.73*	6/21/06	LW457+00	6	1.33
4/17/06	LW533+60		0.82*	6/21/06	LW450+00	6	0.83*
4/17/06	LW530+25		0.66*	6/21/06	LW445+00	6	1.22
4/17/06	LW529+25		0.70*	6/22/06	LW435+00	6	0.84*
4/17/06	LW528+25		0.62*	6/22/06	LW430+00	6	1.08
4/17/06	LW527+25		0.91*	6/26/06	LW420+00	6	0.70*
4/17/06	LW524+80		0.74*	6/26/06	LW415+00	6	0.79*
4/17/06	LW523+80		1.02	6/27/06	LW395+00	6	1.09
4/17/06	LW522+25		1.04	6/27/06	LW385+00	6	0.87*
4/17/06	LW520+67		1.13	6/28/06	LW380+50	6	1.42
4/17/06	LW535+60		1.10	6/28/06	LW380+00	6	0.89*
4/17/06	LW541+15		0.90*	6/28/06	LW375+00	6	1.09
4/17/06	LW542+08		0.96*	6/28/06	LW375+00	4	1.28
4/17/06	LW551+00		0.45*	6/28/06	LW370+00	6	0.65*
4/17/06	LW556+00		0.58*	6/29/06	LW409+50	6	1.39
4/17/06	LW562+00		0.77*	6/29/06	LW402+50	6	1.22
4/18/06	LW521+00	5	1.40	6/29/06	LW402+50	6	0.35*
*** Failing measurements**							

A sample of a data collection sheet and a sample calculation for the sand patch test are included in Appendix C.

Friction

Friction testing of the newly completed PCCP and the existing diamond ground pavement (located in the lanes adjacent to the HOV lanes) were completed on September 13, 2006 using test method ASTM E-274 and a ribbed tire. The friction numbers (FN) for all of the surfaces are shown in Table 6. Values were generally very good with averages ranging from 43.3 to 51.3. The highest average FN occurred in the southbound transverse tining section and the northbound carpet drag section, both with 51.3. The lowest average FN occurred in the transverse tined section with a 43.3. There were only five tests between FN 30 and FN 26 and no values less than 26 for all tests on the HOV lanes. Pavements with FNs below 26 require some type of corrective action; those between 30 and 26 are flagged as potential problem areas. There did not seem to be any trends indicating one finishing type was superior to any other finishing type.

Friction tests were also performed on the existing PCCP lanes adjacent to the new construction. Three lanes northbound and four lanes southbound were diamond ground to remove the rutting caused by studded tires and to improve the ride. The outer two lanes in each direction were also retrofit with dowel bars to restore load transfer at the transverse joints. The FN values for these lanes were somewhat lower than the new construction with averages of 44.1 northbound and 32.9 southbound. Lane 1 in the northbound direction is hot mix asphalt.

Table 6. FNs from testing on September 13, 2006.

Surface Finish	Lane	FN Average	FN Range
Carpet Drag	HOV NB	51.3	36.5 – 58.9
Carpet Drag	HOV SB	50.4	26.2 – 59.2
Longitudinal Tining	HOV NB	44.1	33.4 – 49.2
Transverse Tining	HOV NB	43.3	Single Test
Transverse Tining	HOV SB	51.3	49.7 – 52.9
Diamond Grinding	Lanes 2-4 NB	44.1	28.4 – 65.9
Diamond Grinding	Lanes 1-4 SB	32.9	26.9 – 65.6

Roughness

Roughness measurements were made on September 29, 2006 using the WSDOT Pavement Condition Collection Van. The roughness readings for the HOV lane for each of the special texturing sections in each direction, expressed in IRI (International Roughness Index), are summarized in Table 7. The finishing methods were quite variable with IRI readings from 107 to 144 inches/mile. The lowest and highest roughest readings were obtained on the transverse tined sections. It should be pointed out that there were no surface smoothness readings made by the contractor as a part of this contract. The surface smoothness specification was deleted from the contract documents and no bid item was included for making these measurements.

Table 7. IRI measurements for the NB and SB HOV lane.			
NB			
Finish Type	**Average IRI** (inches/mile)	**Standard Deviation** (inches/mile)	**IRI Range** (inches/mile)
Carpet Drag	115	40	55 – 313
Longitudinal	126	21	82 – 179
Transverse	107	13	100 – 133
SB			
Carpet Drag	112	37	62 – 322
Transverse	144	31	99 – 202

Wear

Wear measurements were also taken on September 29, 2006 using the WSDOT Pavement Condition Data Collection Van. The wear measurements for each finishing method in each direction are summarized in Table 8 and charted in Figure 9. These readings, taken only two months after the completion of the paving, will provide an excellent base line for measuring the amount of studded tire wear that occurs over time.

Table 8. Wear measurements for NB and SB HOV lanes.			
NB			
Finish Type	**INO Average** (mm)	**Standard Deviation** (mm)	**INO Range** (mm)
Carpet Drag	2.7	0.8	1.1 – 5.6
Longitudinal	1.8	0.4	1.2 – 2.7
Transverse	1.7	0.5	1.3 – 2.6
SB			
Carpet Drag	2.0	0.6	1.0 – 4.6
Transverse	2.5	0.5	1.9 – 3.6

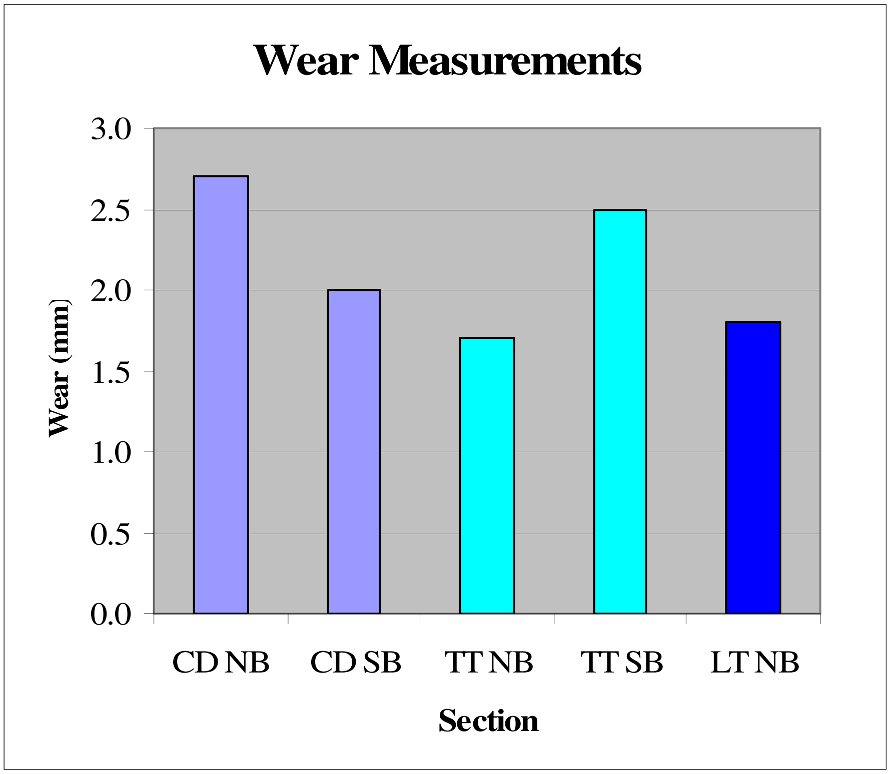

Figure 9. Wear measurements for each texturing method.*

* CD = carpet drag, TT = transverse tining, LT = longitudinal tining

Discussion of Results

The results from the post-construction testing provide a baseline for measurements over the life of the study. The friction numbers are very good for all of the various finishing methods. The high readings in the 50's on the carpet drag sections parallel the measurements from the post-construction testing of the HOV project north of this project (C6757, Federal Way to S. 317th Street HOV Direct Access) that also used a carpet drag finish. The average friction number for the HOV lanes on this project was 51.2. The roughness measurements were disappointing for this project with IRIs in the range of 107 to 144. In contrast, the roughness measurements for the project to the north ranged from 85 to 88. The initial wear measurements on this project were very good with a range of 1.7 to 2.7mm. In contrast, the initial wear readings for the carpet drag project to the north of this project ranged between 2.3 and 3.7 mm.

Through the use of experimental features, WSDOT Construction has learned the importance of including a minimum carpet drag texture and measurement procedure for control. The control on the HOV Stage 4 project relied on visual inspection to obtain the 1.0 mm texture depth, and as can be seen in Table 5, visual inspection resulted in texture depths less than the desired 1.0 mm minimum. Future WSDOT contracts will include both a minimum texture depth and required measurement by the sand patch test to insure that this is achieved.

Future Research

The experimental feature work plan (see Appendix D) calls for this project to be monitored for a period of five years. Data is to be collected twice yearly, spring and fall, to measure the changes in wear and friction resistance. Annual pavement condition survey data will also supplement the twice yearly data collection to provide an overall picture of pavement performance. Annual update reports will be generated as well as a final report at the end of the study period.

APPENDIX A

Contract 6883 Change Order

WASHINGTON STATE

DEPARTMENT OF TRANSPORTATION

CHANGE ORDER

CONTRACT NO: 006883 CHANGE ORDER 38

All work, materials, and measurements to be in accordance with the provisions of the Standard Specifications and Special Provisions for the type of construction involved.

This contract is revised as follows:

DESCRIPTION OF WORK:
Transverse tining, longitudinal tining and carpet dragging methods of finishing PCCP shall be used on this project in the locations specified below.

CONSTRUCTION REQUIREMENTS:
Section 5-05.3(11) of the Standard Specifications for Road, Bridge and Municipal Construction 2002 is supplemented with the following:

In advance of curing operations, where longitudinal tining is required, the pavement shall be given an initial and a final texturing. Initial texturing shall be performed with a burlap drag or broom device that will produce striations parallel with centerline. Final texturing shall be performed with a spring steel tine device that will produce grooves parallel with the centerline. The spring steel tine device shall be operated within 5 inches, but not closer than 3 inches, of pavement edges.

Burlap drags, brooms and tine devices shall be installed on self-propelled equipment having external alignment control. The installation shall be such that when texturing, the area of burlap in contact with the pavement surface shall be maintained constant at all times. Broom and tine devices shall be provided with positive elevation control. Downward pressure on pavement surface shall be maintained at all times during texturing so as to achieve uniform texturing without measurable variations in pavement profile. Self-propelled texturing machines shall be operated so that travel speed when texturing is maintained constant. Failure of equipment to conform to all provisions in this paragraph shall constitute cause for stopping placement of concrete until the equipment deficiency or malfunction is corrected. Spring steel tines of the final texturing device shall be rectangular in cross section, 3/32 to 1/8 inch side, on 3/4 inch centers, and of sufficient length, thickness and resilience to form grooves approximately 3/16 inch deep in the fresh concrete surface. Final texture shall be uniform in appearance with substantially all of the grooves having a depth between 1/16 inch and 5/16 inch.

In advance of curing operations, where carpet dragging is required, the pavement shall be given a single texturing. Texturing shall be performed with a single piece of artificial grass dragged parallel with centerline. The artificial grass shall span the full width of pavement being placed, less one foot on each side, and the length in contact with the concrete being finished shall be adjustable longitudinally as necessary to achieve the required texture. The outside one foot not covered by the carpet drag shall be finished by broom longitudinally. The depth of texture produced by carpet dragging shall be a minimum of 1.0 millimeter as tested using ASTM E965 "Measuring Pavement Micro Texture Depth Using A Volumetric Technique".

Where transverse tining is required, the PCCP finishing shall be done in accordance with Section 5-05.3(11) of the Standard Specifications for Road, Bridge and Municipal Construction 2002.

Finish the LW line with carpet dragging from LW station 346+25 to Bridge 5/504W.
Finish the LW line with longitudinal tining from Bridge 5/504W to the first joint before LW station 564+04.
Finish the LW line with transverse tining from the first joint before LW station 564+04 to LW station 567+04.

Finish the LE line with carpet dragging from LE station 346+20 to Bridge 5/504E.
Finish the LE line with longitudinal tining from Bridge 5/504E to the first joint before LE station 578+18.
Finish the LE line with transverse tining from the first joint before LE station 578+18 to LE station 581+18

MEASUREMENT AND PAYMENT
This is a no cost change order

CONTRACT TIME:
There shall be no change in contract time due to this change order.

APPENDIX B

Cylinder Strength Test Results

Table 9. Compressive and flexural strength test results from C6883, Pierce Co. Line to Tukwila – HOV – Stage 4.				
Date Made	**Compressive Strength (psi)**	**Flexural Strength (psi)**	**Station**	**Cylinder Number**
4/3/2006	6,070	871	LE547+90	1-2
4/3/2006	5,940	861	LE548+50	3-4
4/3/2006	5,940	861	LE551+22	5-6
4/3/2006	5,730	846	LE556+40	7-8
4/5/2006	5,890	858	LE557+50	9-10
4/5/2006	6,270	885	LE558+10	11-12
4/5/2006	5,990	865	LE562+70	13-14
4/5/2006	6,110	874	LE567+70	15-16
4/5/2006	6,630	910	LE573+00	17-18
4/5/2006	6,580	906	LE573+20	19-20
4/5/2006	6,630	910	LE577+85	21-22
4/10/2006	5,630	839	LW566+70	23-24
4/10/2006	6,200	880	LW561+20	25-26
4/10/2006	6,180	879	LW556+60	27-28
4/10/2006	6,430	896	LW551+30	29-30
4/17/2006	5,800	851	LW541+15	31-32
4/17/2006	5,840	854	LW535+60	33-34
4/17/2006	5,460	826	LW530+25	35-36
4/17/2006	5,960	863	LW524+80	37-38
4/18/2006	5,400	821	LW519+30	39-40
4/18/2006	5,730	846	LW513+80	41-42
4/20/2006	5,330	816	LE505+10	43-44
4/20/2006	5,640	839	LE510+60	45-46
4/20/2006	5,120	800	LE516+95	47-48
4/20/2006	5,020	792	LE522+40	49-50
4/20/2006	5,150	802	LE527+60	51-52
4/24/2006	5,210	807	LE533+15	53-54
4/24/2006	5,290	813	LE538+35	55-56
5/1/2006	4,990	789	LE372+90	57-58
5/1/2006	5,420	823	LE378+40	59-60
5/1/2006	5,640	839	LE383+70	61-62
5/2/2006	5,170	804	LE388+80	63-64
5/11/2006	5,640	839	LE394+05	65-66
5/11/2006	5,490	828	LE401+80	67-68
5/15/2006	4,810	775	LE414+50	69-70
5/15/2006	5,070	796	LE420+40	71-72
5/15/2006	5,250	810	LE426+50	73-74
5/16/2006	5,190	805	LE430+10	75-76
5/16/2006	5,060	795	LE435+60	77-78
5/17/2006	5,160	803	LE441+00	79-80
5/17/2006	5,280	812	LE447+95	81-82
5/17/2006	5,220	807	LE453+40	83-84

Table 9. (continued) Compressive and flexural strength test results from C6883, Pierce Co. Line to Tukwila – HOV – Stage 4.				
Date Made	**Compressive Strength (psi)**	**Flexural Strength (psi)**	**Station**	**Cylinder Number**
5/17/2006	5,150	802	LE459+50	85-86
5/18/2006	5,340	817	LE465+50	87-88
5/18/2006	5,730	846	LE470+70	89090
5/19/2006	4,540	753	LE417+15	91-92
5/22/2006	4,290	732	GORE	93-94
5/23/2006	4,650	762	LE473+50	95-96
5/24/2006	5,160	803	LE481+00	97-98
5/24/2006	5,410	822	LE486+50	99-100
5/25/2006	4,370	739	GORE	101-102
5/26/2006	4,700	766	GORE	103-104
5/30/2006	4,730	769	LE396+30	105-106
5/30/2006	5,170	804	LE493+30	107-108
5/31/2006	4,200	724	LE396+20	109-110
6/1/2006	4,280	731	LE405+65	111-112
6/2/2006	4,380	740	LE408+90	113-114
6/5/2006	4,670	764	LW445+70	120-121
6/6/2006	4,070	713	LE451+40	122-123
6/7/2006	4,600	758	LE464+60	124-125
6/8/2006	4,550	754	LE458+15	126-127
6/9/2006	4,590	757	LE546+20	128-129
6/12/2006	4,410	742	LE503+83	130-131
6/19/2006	4,660	764	LW497+00-LW480+15	132-133
6/19/2006	4,800	774	LW497+00-LW480+15	134-135
6/19/2006	5,010	791	LW485+00	136-137
6/19/2006	5,220	807	LW497+00-LW480+15	138-139
6/20/2006	4,750	770	LW480+00-LW464+90	140-141
6/20/2006	5,050	794	LW480+00-LW464+90	142-143
6/20/2006	4,780	773	LW480+00-LW464+90	144-145
6/21/2006	4,690	765	LW480+75	146-147
6/21/2006	4,890	781	LW455+30	148-149
6/21/2006	5,100	798	LW449+95	150-151
6/22/2006	5,130	800	LW443+55	153-154
6/22/2006	5,410	822	LW438+25	155-156
6/22/2006	5,350	817	LW433+05	157-158
6/22/2006	5,280	812	LW427+80	159-160
6/26/2006	4,800	774	LW422+85	161-162
6/26/2006	4,590	757	LW417+65	163-164
6/26/2006	4,870	780	LW412+50	165-166
6/27/2006	5,010	791	LW400+60	167-168
6/27/2006	5,420	823	LW395+25	169-170
6/27/2006	5,680	842	LW389+75	171-172

Table 9. (continued) Compressive and flexural strength test results from C6883, Pierce Co. Line to Tukwila – HOV – Stage 4.

Date Made	Compressive Strength (psi)	Flexural Strength (psi)	Station	Cylinder Number
6/28/2006	4,780	773	LW383+80	173-174
6/28/2006	4,920	784	LW378+15	175-176
6/28/2006	4,410	742	LW372+55	177-178
6/29/2006	4,960	787	LW406+30	179-180
7/6/2006	4,510	750	LW477+00	179-180
7/7/2006	4,020	709	LW478+90	141-142
7/10/2006	5,570	834	LW467+70	143-144
7/11/2006	4,130	718	LW459+20	145-146
7/12/2006	4,620	760	LW464+60	147-148
7/13/2006	5,230	808	LW409+25	149-150
7/14/2006	5,370	819	LW400+00	151-152
7/17/2006	4,770	772	LW417+10	153-154
7/18/2006	4,980	789	LW407+40	155-156
7/19/2006	4,760	771	LW395+60	157-158
7/25/2006	5,010	791	LW508+10	159-160
7/26/2006	5,750	847	LW499+60	161-162
AVERAGE	**5,190**	**805**		

APPENDIX C

Data Collection Form and Sample Calculation for Sand Patch Test

Sand Patch Data Collection Sheet

ASTM E 965- SAND PATCH TEST

$$MATX_d = 4V/\pi D_{avg.}^2$$

Date: ____________
Location: ____________
Operator: _____________
Texture type: _______________________

Trial 1

Volume of glass spheres, V: ___________mm^3

Dia. 1: _______mm Dia. 2: _______mm Dia. 3: _______mm Dia. 4: _______mm

Average Diameter, $D_{avg.}$: [ ] mm

Avg. Macro Texture Depth, $MATX_d$: ____________mm

Trial 2

Volume of glass spheres, V: ___________mm^3

Dia. 1: _______mm Dia. 2: _______mm Dia. 3: _______mm Dia. 4: _______mm

Average Diameter, $D_{avg.}$: [ ] mm

Avg. Macro Texture Depth, $MATX_d$: ____________mm

Trial 3

Volume of glass spheres, V: ___________mm^3

Dia. 1: _______mm Dia. 2: _______mm Dia. 3: _______mm Dia. 4: _______mm

Average Diameter, $D_{avg.}$: [ ] mm

Avg. Macro Texture Depth, $MATX_d$: ____________mm

Trial 4

Volume of glass spheres, V: ___________mm^3

Dia. 1: _______mm Dia. 2: _______mm Dia. 3: _______mm Dia. 4: _______mm

Average Diameter, $D_{avg.}$: [ ] mm

Avg. Macro Texture Depth, $MATX_d$: ____________mm

Texture Calculations

The volume of the canister was calculated to be:

V = 34.1 and when converted to mm^3 and equals** 34,100**.

$MATX_d = 4V/\pi D_{avg.}^2$

Example

Trial 1

Volume of glass spheres, V: **34,100** mm^3

Dia. 1: **201** mm Dia. 2: **198** mm Dia. 3: **210** mm Dia. 4: **195** mm

Average Diameter, $D_{avg.}$: **201** mm

$$MATX_d = 4V/\pi D_{avg.}^2$$

(4 x 34,100) / (3.14159) x (201 x201)

136,400 / (3.14159 x 40,401)

136,400 / 126,923.49 = 1.07

APPENDIX D

Experimental Feature Work Plan

Washington State Department of Transportation

WORK PLAN

PCCP Features

(Surface Smoothness and Noise)

I-5, Pierce County Line to Tukwila I/C – HOV - Stage 4
Milepost 139.06 to Milepost 144.75

Prepared by

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Washington State Department of Transportation

October 2005

Introduction

Washington State Department of Transportation's (WSDOT) Portland Cement Concrete Pavement (PCCP) construction program has been relatively small since the construction of the Interstate system in the 1960's and early 70's. As many of these early pavements deteriorate and require reconstruction, the best possible construction practices will be essential in order to provide pavements that will last 50 years or longer.

One of the challenges facing WSDOT is to reduce the excessive wear concrete pavements received from studded tires. An Experimental Feature "Combined Aggregate Gradation for Concrete Pavements" is under study and is investigating the use of a combined aggregate gradation to curb the effects of studded tire wear. An additional WSDOT study involves the rates of stud wear on the Specific Pavement Studies (SPS) located on SR 395 south of Ritzville. To date there is definitely less wear due to studded tires in the 900-psi section as compared to the lower strength sections. Further, the tine grooves are still apparent in the high strength sections and are, in essence, gone from the lower strength ones. While these observations are far from conclusive, WSDOT wishes to explore the effects of higher strength PCCP mixes.

Another challenge observed with WSDOT PCCP construction has been with providing smooth riding surfaces, particularly in urban areas. WSDOT has built several pavements in recent years where bonuses have been paid to contractors for satisfying the smoothness specifications, however, in some cases the roadway is still perceived rough. WSDOT's current smoothness requirement is based on a 0.20 inch blanking band with an allowable daily profile index of 7.0 inches per mile or less.

The following sections highlight WSDOT current research efforts:

I-90 – Argonne to Sullivan

An experimental feature, I-90 - Argonne to Sullivan Experimental Feature, MP 287.98 to MP 292.16, is underway in the Eastern Region to consider PCCP features beyond the 2002 WSDOT Standard Specifications. The eastbound lanes of this feature were paved in the summer of 2004. Included in this study is the use of a carpet drag finish, increasing the flexural strength of the PCCP, and providing a zero blanking band for measuring surface smoothness. Following construction of the PCCP, the influences from the carpet drag finish and increased flexural strength specification on the pavement will be monitored to determine its ability to resist surface abrasion. Additionally, the results of using a zero blanking band to determine smoothness will be analyzed and compared with profilogragh results using the 0.20-inch blanking band.

I-5, Federal Way – South 317th Street HOV Direct Access

The I-5, Federal Way – South 317th Street HOV Direct Access project investigates the use of a carpet drag finish placed in Western Washington. This project reconstruction and rehabilitation of 1.49 miles of southbound I-5. The reconstruction portion of the contract is 0.60 miles long and places full width 13 inches (1.08’) of PCCP over 4.2 inches (0.35’) of asphalt concrete over 4.2 inches (0.35’) of crushed surfacing. The total 50-year design ESALs for the single direction traffic are approximately 200 million. The experimental features, constructed during the summer 2005 incorporated the carpet drag texture on the entire mainline pavement. Preliminary results indicate that a smooth PCCP surface with good frictional characteristics was obtained.

Quiet Pavement Pilot Programs

The Federal Highway Administration has changed its noise policy to allow states to take into consideration the effects of quiet pavements as noise mitigation with enough supporting data. The process for state DOT's to utilize pavement type to mitigate noise is found in the January 19, 2005 Memorandum (http://www.fhwa.dot.gov/environment/noise/qpppeml.htm) titled "Highway Traffic Noise – guidance on Quiet Pavement Pilot Programs (QPPP) and Tire/Pavement Noise Research."

The QPPP is intended to demonstrate the effectiveness of quiet pavement strategies and to evaluate any changes in their noise mitigation properties over time. Current knowledge on changes over time is extremely limited. Thus, the programs will collect data and information for at least a 5-10 year period, after which the FHWA will determine if policy changes to a State DOT(s) noise program are warranted.

The intent of the proposed experimental section is to allow the additional placement of a carpet drag and longitudinal tined surfaces in Western Washington. Rutting/friction and noise measurements will be taken over time. Currently, WSDOT does not have a means for collecting noise information, however, there is discussion between the Materials Laboratory and Environmental Noise Quality to purchase equipment. The key item for WSDOT is to place a concrete pavement in Western Washington to compliment the work being performed on I-90 in Spokane. The rutting and friction data will be valuable information as WSDOT begins a QPPP.

Scope

This project involves the construction of HOV lanes and the rehabilitation of 5.69 miles of north and southbound I-5. The pavement section for the HOV lanes will consist of 13 inches

(1.08’) of PCCP over 4.2 inches (0.35’) of asphalt concrete over 4.2 inches (0.35’) of crushed surfacing. The total 50-year design ESALs for the single direction traffic are approximately 200 million. The experimental features will be incorporated over the project length.

Carpet Drag and Longitudinal Tining

The final pavement surface texture will be obtained by drawing a carpet drag or longitudinal tines longitudinally along the pavement before the concrete has taken its initial set. The carpet drag will be a single piece of carpet of sufficient length to span the full width of the pavement being placed and adjustable to allow up to 4 feet longitudinal length in contact with the concrete being finished. The target depth of the carpet drag will be a minimum of 1.0 millimeter. Sand patch tests will be conducted by Materials Laboratory personnel to verify the texture depth of the carpet drag sections. The longitudinal tines will be uniformed spaced metal tines. ACPA is currently researching the specification that promises to provide the quietest surface. This specification will be provided to the Contractor as soon as it is obtained.

Initial WSDOT analysis shows that the carpet drag finish provides an equal or better skid resistance than normal WSDOT transverse tined pavements. This is significant considering studded tire wear normally removes transverse tining 3 to 4 years after placing PCCP.

Mix Design

The mix design requirements will utilize PCCP concrete that has a 14-day target flexural strength of 650 psi as specified in Section 5-05 of the 2004 WSDOT Standard Specifications.

Test Section

Approximately one half of the HOV lane in each direction will utilize the carpet drag finish and the other half will receive the longitudinal tining finish.

Control Section

A minimum of 300 feet of each HOV lane in each direction will be constructed with a transverse tined finish to serve as a control section for the longitudinal tining and carpet drag finished test sections**.** WSDOT Standard Specifications will be followed for the depth and spacing of the tines.

Construction

Concrete will be placed by a slip form paver. Except as indicated, 2004 WSDOT Standard Specifications will apply.

Staffing

The Region Project office will coordinate and manage all construction aspects. Representatives from WSDOT Materials Laboratory (one or two persons) will also be involved with documenting the construction.

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Testing

The completed PCCP will be skid tested to determine friction values. The friction values will be measured twice a year on each of the test sections for the duration of the experiment. Pavement condition survey results will be collected on an annual basis as well as rutting and ride measurements. These tests will measure any changes in performance of the pavement with time as a result of studded tire wear.

Reporting

An "End of Construction" report will be written following completion of the project. This report will include construction details, material test results, and other details concerning the overall process. Annual summaries will also be conducted over the next five years. At the end of the five-year period, a final report will be written which summarizes performance characteristics and future recommendations for use of this process.

Cost Estimate

Construction Costs

This contract is currently under construction. The concrete contractor has agreed to provide the carpet drag at no cost to WSDOT.

Testing Costs

Condition Survey – will be conducted as part of statewide annual survey, no cost.

Rut Measurements – 10- surveys (2 hours each) requires traffic control = $12,000

Friction Measurements – 10 surveys done in conjunction with annual new pavement friction testing, no cost.

Noise Surveys – WSDOT is currently pursuing purchasing noise-monitoring equipment. The cost of this equipment is not included in this experimental feature, as this equipment will be used throughout Washington State once noise monitoring on a regular basis begins. However, about $5,000 is anticipated for funds necessary to monitoring noise for periodic surveys on this section of I-5.

Report Writing Costs

Initial Report – 20 hours = $1,500
Annual Report – 5 hours (1 hour each) = $500
Final Report – 10 hours = $1,000

TOTAL COST = $20,000

Schedule

Construction Date: October 2005

Date	Condition Survey (Annual)	Rut & Friction Measurements (Annual)	End of Construction Report	Annual Report	Final Report
October 2005		X	X		
Spring 2006	X	X		X	
Fall 2006	X	X		X	
Spring 2007	X	X		X	
Fall 2007	X	X		X	
Spring 2008	X	X		X	
Fall 2008	X	X		X	
Spring 2009	X	X		X	
Fall 2009	X	X		X	X