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Friction Restoration of Pavements with Polished Aggregates

Study SD90-16
Final Report

Prepared by
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Office of Research
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DISCLAIMER

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This work was performed under the supervision of the SD90-16 Technical Panel:

Larry Engbrecht . . . Materials & Surfacing
Jim Hammell . . . . Materials and Surfacing
David Huft . . . . Office of Research
Dennis Landguth . . . . Rapid City Region
Charles McFarling . . . . . . Data Inventory

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16. Abstract

This research examines possible means of maintaining or restoring the skid resistance of Portland Cement Concrete pavements (PCCP) built with polish-susceptible aggregates. Several different methods of skid restoration were examined including shot blasting, transverse grooving and application of a rubberized asphalt chip seal (RACS). Neither of the first two methods appears capable of restoring skid resistance (as measured by ASTM E501) for any significant period although both markedly improve the rate of water removal. The RACS provided a long term improvement in skid resistance but its use should be limited due to concrete durability concerns.

The primary means for extending acceptable skid resistance adopted by SDDOT in the mid-1970's was the use of astroturf drag and tined finish both for improved skid resistance and for reduction in hydroplaning susceptibility. An examination of the actual skid resistance history of projects built with polishing aggregates and with and without astroturf drag/tining indicates that there is no appreciable extension of higher friction values where tining is used and that the rate of friction loss is primarily a function of traffic.

Shot blasting was also used to restore skid resistance on asphalt pavement chip seals where severe flushing had occurred. The method appears to provide a straightforward means of restoring friction to these pavements by removing excess asphalt and exposing the chips.

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Executive Summary

In 1981 a total of 77 lane-miles of Interstate 90 from the Lawrence County line to Ellsworth Air Force Base just east of Rapid City, SD were diamond ground to remove a severe longitudinal depression (rut) in both east and westbound driving lane wheel paths. This procedure is routinely used on asphalt concrete pavements as a temporary means of eliminating rutting, but the unusual thing about this particular problem was the fact that all of the 77 miles ground were portland cement concrete (PCC) pavement. Although Minnekahta limestone, the coarse aggregate used in these pavements, has excellent thermal and durability characteristics, it is extremely susceptible to polishing under heavy traffic. The diamond grinding provided a temporary restoration of skid resistance but the wheel paths of the section of pavement between Rapid City and Ellsworth Air Force Base where traffic was heavy were polished smooth within a year and a half. This research was begun to determine if acceptable skid resistance could be restored to these PCC pavements through some type of mechanical treatment. The research also investigated the effectiveness of astroturf drag and tining, which was begun experimentally in 1976, as a means of retarding the degradation of skid resistance in PCC pavements built with polishing aggregates.

The primary method for skid restoration investigated was the Skidabrader, a shot blasting machine manufactured by the Humble Equipment Company, Inc. of Ruston, Louisiana. This machine throws high speed steel shot at the pavement surface while collecting rebounding shot and abrasion dust with a vacuum collector and is capable of generating micro- and macrotexture important for skid and hydroplaning resistance. The Skidabrader was not able to produce a substantial improvement in skid values on the original test pavement which had been diamond ground previously. A second series of test sections on a pavement which had no prior treatment gave somewhat better results with improved skid resistance over a five year period.

The Skidabrader was able to equal transverse grooving in terms of reduced hydroplaning potential as measured by the outflow procedure, which records the time necessary for a fixed volume of water to run off the pavement surface. Even the transverse grooving did not continue to conserve the initially higher skid resistance for any period of time but the rapid channeling effect of the grooves did maintain friction values slightly above the acceptable threshold. Either method appears to be an effective means of restoring skid resistance.

The use of astroturf drag and tining does not appear to have a profound effect on polishing of PCC pavements with Minnekahta limestone. The primary factor influencing the rate of skid loss is the total number of wheel passes, and average daily traffic (ADT) is directly related to how long it takes for a given pavement to reach unacceptable friction values. Analysis of a series of PCC pavements incorporating limestone shows a strong correlation between skid numbers and pavement age with a categorical dependence on ADT. These pavements break out into two groups with a change in polishing behavior occurring at approximately 3000 ADT with the lower ADT pavements taking considerably longer to reach unacceptable skid values. The skid performance curves for these two groups can be used to roughly predict the average time required for friction values to fall to a value of 30 as determined by ASTM E274 using a ribbed tire (ASTM E501). These estimates do not take into account either the total wheel passes or the amount of winter maintenance occurring on a given project, both of which may effect the rate of polishing. The models give the following average projections:

ADT	Time to Skid Number < 30
> 3000	15.6 years
< 3000	29.1 years

One project on I90 at mileage reference marker (MRM) 32.85 was excluded from the analysis due to its having greater polish resistance. An investigation of the factors responsible identified the cause as the presence of 20-30% durable siliceous coarse aggregate in the concrete. A series of test sections incorporating various amounts of a durable, non-polishing coarse aggregate mixed with limestone have been constructed on a high ADT section of pavement. Skid behavior is being monitored to determine an optimum mixture for long term skid performance in research project SD93-01, *Alternative Methods and/or Mix Designs for Constructing More Skid Resistant Limestone PCC Pavements.*

A rubberized asphalt chip seal (RACS) was also placed on I90 adjacent to the shot blasting and transverse grooving sections and provided superior, consistent skid resistance. Unfortunately, the use of a full width RACS is not recommended due to alkali-silica reactive fine aggregate in much of the polished PCC concrete. Development of a partial application of a RACS on or across the wheel paths could provide the optimum solution to the polishing aggregate problem, but further work would be necessary before this strategy can be adopted.

The Skidabrader was also successfully employed to restore skid resistance on flushed chip sealed AC pavements. The treatment removed a major proportion of the excess surface asphalt, exposing the original chip seal and providing a significant improvement in skid resistance.

Conclusions

1. The Skidabrader shot blasting technique does not restore friction numbers for more than six months on a PCC pavement containing Minnekahta limestone where diamond grinding was done previously. It does, however, appear to maintain friction values above 30 on previously untreated polished PCC pavement for 5 years or more.

2. The Skidabrader shot blasting technique appears to be a viable means of restoring hydroplaning resistance to polished PCC pavements where macrotexture is no longer available to channel water. The Skidabrader control parameters—speed and impact energy—can be set to yield uniform and reproducible surface texture, but they must be determined for each treated pavement.

3. Astroturf drag/tining does not appreciably slow the rate of polishing on PCC pavements containing susceptible aggregate. The degree of polishing over time is a function of time and traffic with limestone pavements having ADT >3000 vehicles per day polishing to unacceptable skid values within 15-20 years and <3000 taking 30 years or more to reach the same point.

4. Transverse grooving is an extremely effective means of restoring hydroplaning resistance and generating a channeling macrotexture on a polished pavement. Unfortunately, transverse grooving does not restore skid numbers for a significant period of time but it does appear to be able to maintain values slightly above the acceptable threshold for 5 years or more.

5. The most effective means of restoring skid resistance is the rubberized asphalt chip seal which is capable of maintaining high skid resistance indefinitely. Although it is more expensive than any other method, a partial RACS may solve this problem while allowing the pavement to transmit moisture normally.

6. The Skidabrader is capable of restoring acceptable skid resistance to a flushed AC chip seal for a period in excess of three years (possibly five years or more) and can be used as an alternative to resealing flushed pavements.

Recommendations

1. The Skidabrader should be approved as an alternate treatment to transverse grooving for skid restoration of polished PCC pavements if appropriate with each treatment specifically optimized for the pavement being treated using sand patch, outflow and skid test results to set the operating parameters.

2. Astroturf drag/tining treatment should continue on all PCC pavements with the added assurance that the sand used in all concrete pavement mix designs is at least 30% siliceous material (as recommended by FHWA) to maximize microtexture life.

3. A series of test sections incorporating various amounts of a durable, non-polishing coarse aggregate mixed with limestone should be constructed on a high ADT section of pavement and its skid behavior monitored to determine an optimum mixture for long term skid performance. This research is already underway as project SD93-01, *Alternative Methods and/or Mix Designs for Constructing More Skid Resistant Limestone PCC Pavements.*

4. A series of test sections using partial application patterns of rubberized asphalt chip seals (RACS) or other available systems (polymer chip seals) should be constructed on polished PCC pavements to determine the feasibility of developing an effective skid restoration process.

5. The Skidabrader should be allowed as an alternate to the following on flushed asphalt concrete pavements: chip sealing flushed AC pavements which have already been chip sealed with the treatment parameters determined on a project basis; mill and chip seal; polymer modified chip seal; construction of stone mastic asphalt (SMA) wearing course.

Introduction

In 1981 a total of 77 lane-miles of Interstate 90 from the Lawrence County line to Ellsworth Air Force Base just east of Rapid City, SD were diamond ground to remove a severe longitudinal depression (rut) in both east and westbound driving lane wheel paths. This procedure is routinely used on asphalt concrete pavements as a temporary means of eliminating rutting, but the unusual thing about this particular problem was the fact that all of the 77 miles ground were portland cement concrete (PCC) pavement. Although Minnekahta limestone, the coarse aggregate used in these pavements, has excellent thermal and durability characteristics, it is extremely susceptible to polishing under heavy traffic. The diamond grinding provided a temporary restoration of skid resistance but the wheel paths of the section of pavement between Rapid City and Ellsworth Air Force Base where traffic was heavy were polished smooth within a year and a half. This research was begun to determine if acceptable skid resistance could be restored to these slippery PCC pavements through some type of mechanical treatment. The research also investigated the effectiveness of astroturf drag and tining, which was begun experimentally in 1976, as a means of retarding the degradation of skid resistance in PCC pavements built with polishing aggregates.

Objectives

The objectives of this research were:

1. To determine if shot blasting is capable of restoring skid resistance for an extended period on polished pavements.

2. To determine if current methods (astroturf drag, tining) are adequate means of maintaining skid resistance.

3. To determine the effect of transverse grooving on skid resistance.

4. To develop guidelines for skid restoration using the shot blasting technique.

Tasks

The following tasks were performed:

1. Monitor skid performance on existing test sections treated with shot blasting and transverse grooving.

2. Analyze the skid history since construction of two PCC pavements built at the same time using limestone with and without astroturf drag and tining.

3. Install new test sections using a shotblaster specifically designed for skid restoration.

4. Identify operational procedures which can be used to successfully restore skid resistance.

Skid Restoration of Portland Cement Concrete

One method of skid restoration recently developed involves the use of a modified shot blasting technique to abrade the polished surface of the concrete and restore both macrotexture and microtexture. This type of machine was originally developed as a highly efficient surface cleaner prior to bridge and pavement PCC overlays. The shotblaster uses fine steel shot propelled at speeds in excess of 250 miles/hour to generate new surface texture on the pavement. After the shot impacts the surface, it and the extremely fine dust resulting from this abrasive action are pulled by vacuum through a series of screens, which trap the steel shot, into a truck-mounted dust collector. The area being treated is surrounded by a shroud which encloses and seals that portion of the pavement, allowing dust-free operation and minimal stray shot. Each pass of the shotblaster treats a swath of pavement 6' wide.

Initial Shotblaster Test Sections

On October 2-4, 1989 a series of test sections using the Skidabrader shotblaster manufactured by Humble Equipment Company, Ruston, Louisiana were installed on a one mile stretch of Interstate 90 in the eastbound lane (MRM 64.2-MRM 65.2) between Rapid City and

Ellsworth Air Force Base. This site was excluded from a transverse grooving project completed in 1989; a portion of the transversely grooved pavement was included in the skid testing program so the effects of transverse grooving could be monitored simultaneously. The shot blast test sections lie immediately east of a rubberized chip seal placed in 1986. This section was also tested as part of the research. The 26 year old PCC pavement on this portion of Interstate incorporated Minnekahta limestone, which tends to polish in the wheel paths under heavy traffic like that between Rapid City and the air base (ADT 6862). The pavement was longitudinally ground in 1981 in the driving lane to remove a severe wheel path rut. The grinding resulted in a short term improvement in skid resistance but no evidence of the grinding remains visible in the wheel paths.

The amount of abrasive energy delivered by the Skidabrader is a function of the horsepower used to deliver the shot and the speed at which it traverses the pavement. A sequence of eight test sections, each approximately 300 feet in length, were laid out in the left wheel path of the eastbound driving lane. Preliminary skid testing (ASTM E274) using a ribbed tire (ASTM E501) was conducted on all sections prior to application of the shot blasting. The horsepower used to deliver the shot was held constant while the speed of the Skidabrader was decreased in increments of 5 feet/minute for each test section from its starting speed of 50 feet/minute. The final test section was treated at a speed of 15 feet/minute. After completion of the test sections two skid tests were run on each section to determine the appropriate speed to use for treatment of the remaining pavement. Macrotexture depth measurements (ASTM E965) were also made on several test sections. These results are shown in Table I and, graphically, in Figure 1.

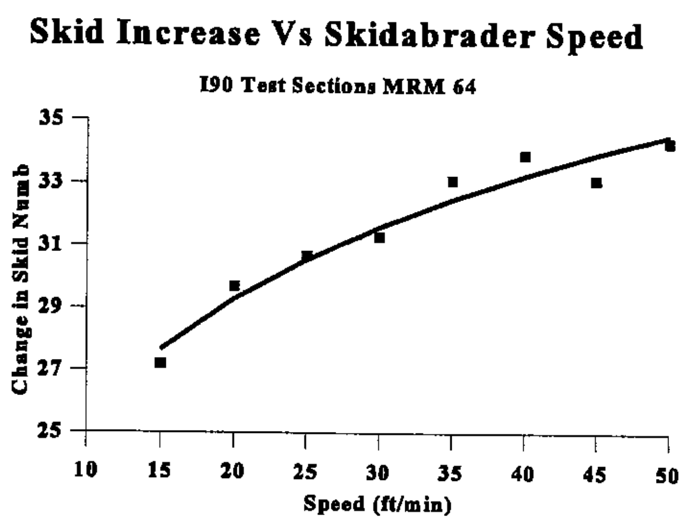

Figure 1: Initial Skidabrader Results

Skid numbers were expected to increase gradually with decreasing speed as more energy was applied to the pavement subsequently producing more micro- and macrotexture. Such was not the case, with the measured friction values actually appearing to decrease with decreasing speed. The values in Figure 1 were adjusted for initial skid resistance by subtracting each pretreatment skid from the posttreatment value to correct for variations in the original skid values. The resulting plot shows a very strong relationship between the increase in skid and the speed of the shotblaster. Based on these results the Skidabrader speed chosen for treating the remaining pavement was 50 feet/minute. Because there appeared to be a directional bias in the way the shot impacted the pavement an additional pass was also made at 50 feet/minute with the machine traveling in the opposite direction.

Table I: Skid Numbers After Initial Skidabrader Treatment

Skidabrader Speed (ft/min)	Production Rate (yd^2/min)	Average Skid Number		Macrotexture Depth (inches)
		Pre-treatment	Post-treatment	
50	33.3	26.2	60.5	.0597
45	30.0	26.2	59.3	N/A
40	26.7	26.6	60.5	N/A
35	23.3	25.9	59	N/A
30	20.0	27.8	59.1	N/A
25	16.7	26.3	57	.0653
20	13.3	27.9	57.6	.0684
15	10.0	25.5	52.7	.0790
2/50	16.6	26.5	55.2	N/A
Average		26.6	58.2	

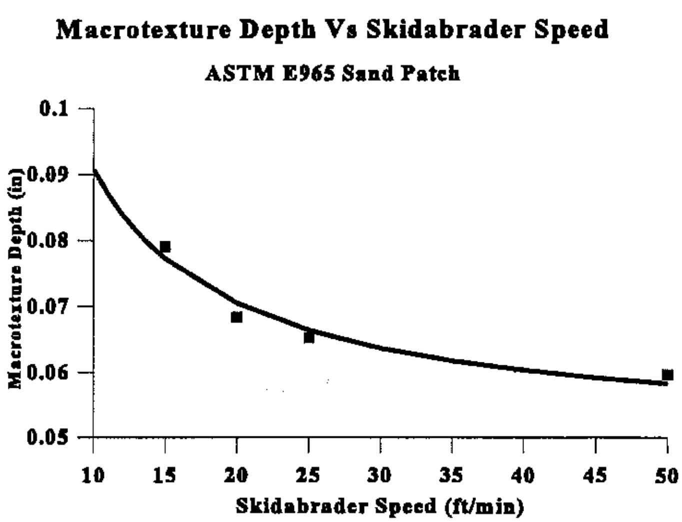

Figure 2: Macrotexture Depths

The really unusual thing about these results was the opposite effect observed when the ASTM E 965 macrotexture depth values were plotted against the Skidabrader speed as shown in Figure 2. The macrotexture generated increased as a function of the energy applied to the pavement and inversely as the speed. Presumably the sustained shot blasting which created this macrotexture also reduced the residual microtexture, yielding lower friction values as the Skidabrader speed was reduced.

Although these initial values were excellent the long term skid improvement remained in question. A monitoring program was established to track the degradation of the skid resistance over the course of the next year. Unfortunately the friction numbers rapidly decreased with time, indicating that the skid improvement was merely a transient occurrence and the pavement was unable to retain the microtexture necessary for adequate skid resistance. Friction values decayed exponentially with respect to time. Table II shows the fairly rapid loss in skid resistance over the first year after treatment and Figure 3 illustrates a typical friction decay curve for the test section treated at 30 feet/minute. All of the test sections lost skid resistance in a similar way but at varying rates. The general equation used to fit these curves was:

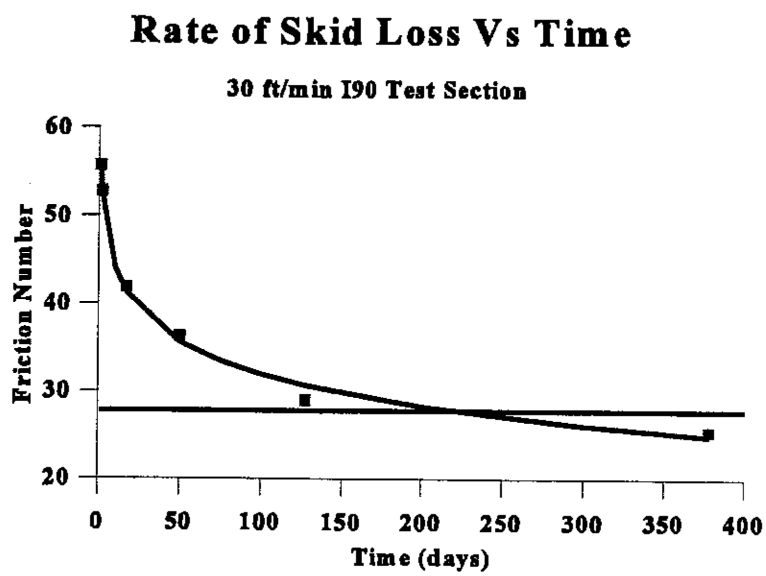

Figure 3: Rate of Skid Loss

$$Friction\ Number = \alpha + \beta\ \ln(Time)$$

Table II: Decay of Friction Values with Time

Speed	10/2/89	10/3/89	10/4/89	10/19/89	11/21/89	2/6/90	10/15/90
50	60.5	53.9	52.8	42.3	39.2	27	26.6
45	59.3	52.1	53.2	41.9	36.8	27	25.4
40	60.5	56.3	54.6	43.7	36.9	27	27.2
35	59	54.6	56.7	43.1	36.9	28	27.3
30	59.1	55.7	52.8	41.9	36.3	29	25.5
25	57	53.3	50.0	41.6	36.2	28	25.9
20	57.6	51.2	54.6	41.3	35.8	28	24.1
15	52.7	N/A	55.1	41.4	33.7	29	26.9
2/50	N/A	55.2	54.9	41.7	36.7	30	26.9
Average	59.0	53.8	53.5	42.2	36.5	28.1	26.2

All decay curves fit this equation adequately, allowing a comparison of the rate of decay (the β term in the equation) with the speed of the Skidabrader and the amount of energy applied to the PCC pavement. A plot of β values against speed in Figure 4 displays a direct relationship between the loss of skid resistance and the treatment speed employed except for speeds greater than 40 feet/minute. It is interesting to note that the slowest rates of friction loss occur when the highest and lowest speeds were employed. The response to the shot blasting treatment was linear below a speed of 45 feet/minute except for the value obtained at 25 feet/minute which was

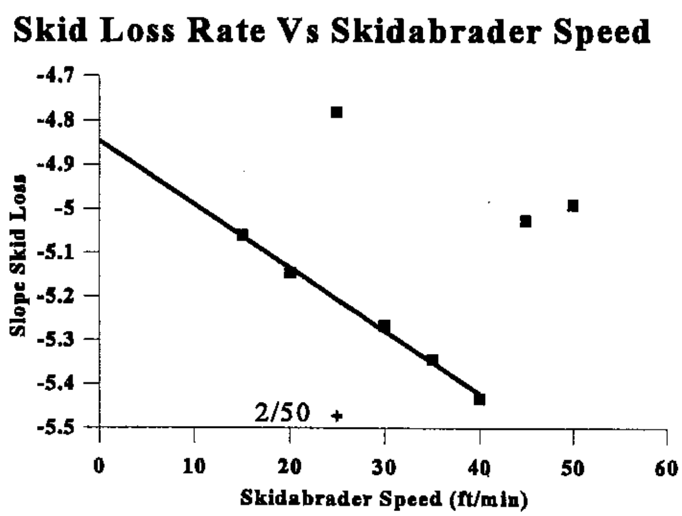

Figure 4: Skid Loss Rate

probably invalid. (The Skidabrader lost stability while treating this section of pavement and had to make repeated passes after dumping the bulk of its shot load onto the pavement.) Although none of the treatments were able to provide any significant improvement beyond six months the data strongly suggest that, all else being equal, applying either minimal or maximum energy to a polished concrete pavement may give the best results in terms of long term dry pavement skid improvement. High speed abrasion has a decided advantage in terms of production rate and overall cost and probably leaves more durable microtexture because it does not remove as much surface mortar. Low speed, high impact abrasion creates a well defined macrotexture which should definitely decrease hydroplaning potential.

Outflow Meter Test Results

Conventional skid testing does not demonstrate a great deal of sensitivity to macrotexture and potential hydroplaning response, so outflow measurements were taken on the various test sections two years after treatment. The outflow device borrowed from the Federal Highway Administration consists of a plastic tank with two parallel electrodes embedded in the tank wall a fixed distance apart connected to a timing device.

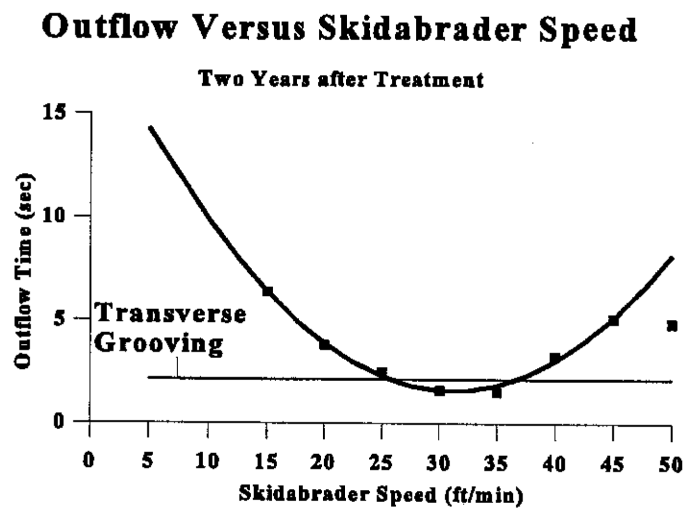

Figure 5: Outflow Test Results

A flexible rubber gasket at the base of the tank allows for a watertight fit against the pavement being tested. Turning the device on allows the water inside to flow onto the pavement and the period of time it takes for the water to go from the top electrode to the bottom electrode provides a measure of the outflow capacity of the pavement which directly relates to hydroplaning potential. Test results indicate an optimum application range of 30-35 feet/minute to achieve the most effective macrotexture of 0.062-0.064 inches. At low speed and high impact, the flow drops off, probably due to formation of pockets in the pavement surface with minimal channelization.

Additional PCC Test Sections on I90

The above test sections established in 1989 were a worst-case application of the Skidabrader technology as the pavement had already been diamond ground prior to the test exposing the large coarse aggregate (top size 2") and minimizing the potential for improving microtexture by exposing fine aggregate and mortar. A further test was conducted in October, 1990 on a section of Interstate 90 (MRM 67-ADT 4365) several miles to the east of the original test location. Three 500' sections of PCC pavement with pre-treatment friction values of 31 were treated at speeds of 40, 50 and 60 feet/minute and the resulting skid numbers were monitored over a period of almost five years. Figure 6 shows the results of the treatment and indicates a substantial decrease in the rate of skid loss over time compared to the original test results. Conceivably, a treatment at an appropriate speed to produce a macrotexture depth of .062-.064 inches on polished PCC pavement containing limestone not previously diamond ground could be an effective means of restoring skid resistance for a period of five years or more. An additional benefit would be gained by generating sufficient macrotexture to provide rapid water channelization and prevent hydroplaning. Current cost estimates for using the Skidabrader to restore texture on PCC pavements range from $1.25-$2.00/yd^2 depending on volume, logistics, production rate and work limitations. This equates to 50-75% of the cost of transverse grooving at current cost levels.

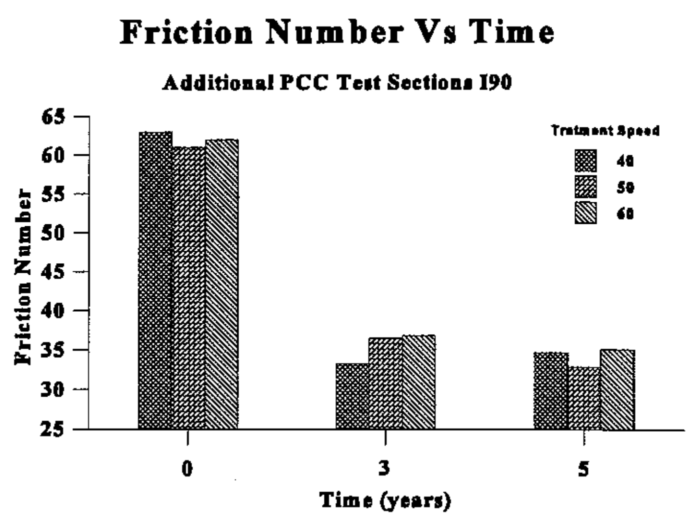

Figure 6: Friction Numbers

Effect of Astroturf Drag/Tining on Skid Resistance

In 1976 a research project was begun by SDDOT to evaluate the benefits of texturing the plastic concrete surface with a combination of astroturf drag and tining. The final report, *Portland Cement Concrete Pavement Steel Tine Surface Finish*, was completed in 1982 and recommended the adoption of both treatments as a routine surface finish for all PCC pavements. Unfortunately the aggregate used in the PCC test pavement was an hard, siliceous gravel and not limestone. The results of this research were promising and the value of using astroturf drag and tining to develop microtexture and macrotexture, respectively, is not in doubt. The question remains, however, as to the ability of these surface finishing techniques to retard the polishing of a pavement containing limestone or some other polish-susceptible aggregate.

An astroturf drag is beneficial to the skid resistance of a concrete pavement surface due to the rough microtexture it generates. Under friction-testing conditions using a ribbed tire this uneven surface acts to break up the water film which would otherwise form. The ability of this microtexture to resist abrasion is a key factor in determining the long term skid resistance properties of a pavement. One of the goals of this research was to evaluate the effects of astroturf drag and tining on the rate of skid loss in PCC pavements with Minnekahta limestone coarse aggregate.

Skid Resistance of Tined PCC Pavements with Limestone

Two projects on I90 were identified as ideal candidates for measuring the polishing behavior of PCC pavements with limestone, tining and astroturf drag. The first was a short reconstructed segment in the eastbound lane of I90 near Tilford (MRM 37.04) built in 1981. The pavement was a 10" jointed plain concrete 24' wide finished with astroturf drag/tining. The second project lay directly west of the first (MRM 32.85) in the eastbound lane and was a continuation of the reconstruction completed in 1983.

Average skid numbers for each project were obtained from the pavement friction testing logs. These values are shown below for the years where data were available. No data are available for either project immediately after construction. Figure 7 shows a plot of the friction numbers versus the ages of the pavements and indicates that the use of astroturf drag/tining

Table III: Skid History for I90 Tined Projects

Date Tested (ASTM E501)	MRM 32.85 ADT 5030	MRM 37.04 ADT 4765
June 16, 1983		43.7
June 19, 1984	51.8	42
June 16, 1987	49.8	40.3
May 23, 1990	46.9	38
June 16, 1992	40.9	34.5

does not prevent or even substantially reduce the rate of polishing for PCC pavements under traffic. The rate of polishing for the pavement section beginning at MRM 32.85 is much lower than that at MRM 37.04. The fact that the pavement at MRM 32.85 was built two years after the one at MRM 37.04 does not explain the difference as the plot is normalized to age. Both pavements exhibit an exponential decay of friction values with essentially parallel slopes. A search for a possible reason for the performance difference yielded one major contrast between the two projects, coarse aggregate source. The limestone for the MRM 37.04 project was quarried rock from Rapid City whereas the MRM 32.85 project incorporated a crushed pit run material composed primarily of Minnekahta limestone but containing 20-30% crushed igneous gravel. The presence of this hard, polish-resistant gravel, even in these relatively small quantities, is consistent with the decrease in the rate of skid resistance loss.

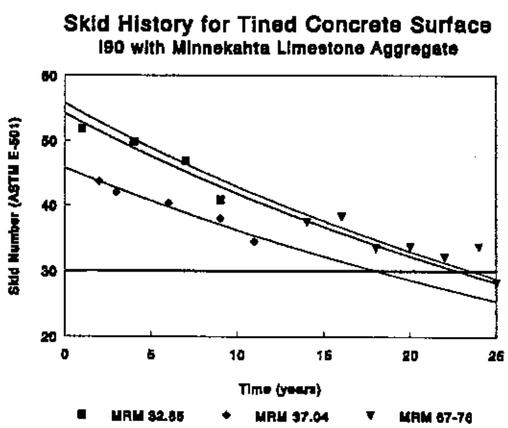

Figure 7: Skid History for I90 Pavements

The third line in the figure is a plot of the average skid numbers for a section of I90 east of Rapid City from MRM 67.14 to MRM 76.33. This pavement was built in 1963 as part of the original Interstate and was finished with a burlap drag. The fact that its skid loss follows a parallel exponential decay similar to the other projects at a somewhat lower loss rate is indicative of comparable polishing occurring on both the newer projects and the 31 year old pavement. The major difference between the MRM 37.04 project and the MRM 67.14 project is the average daily traffic count for each. The first has an ADT of 4765 while the second is only 3765. In terms of total cumulative vehicle passes, especially considering the substantial growth in traffic since the Interstate was constructed, the project at MRM 37.04 has probably experienced a significant portion of vehicles compared to the older pavement. The explanation for the slower rate of polishing on the MRM 67.04 project would be its much lower ADT.

Because the use of astroturf drag/tining does not appear to have a profound effect on polishing of PCC pavements with Minnekahta limestone the question of how long acceptable skid resistance can be maintained on these pavements arises. The primary factor influencing the rate of skid loss is the total number of wheel passes, and ADT should be directly related to how long it takes for a given pavement to reach unacceptable friction values. Table IV shows the 1990 friction values for a series of PCC pavements incorporating limestone as well as the ADT and number of trucks. A statistical analysis of the data showed a strong correlation between skid numbers and pavement age with a categorical dependence on ADT as shown in Figure 8. Although both groups of pavements followed an exponential skid decay model the break in polishing rate appears to occur at approximately 3000 ADT with the lower ADT pavements taking considerably longer to reach unacceptable skid values. Again the 31 year old project from I90 east of Rapid City is included for reference and its location parallel to and between the two groups is consistent with the rate of polishing as a result of cumulative wheel passes. This project has a current ADT of 3765 but during most of its service life the ADT would have been below 3000. The I90 MRM 32.85 project was excluded from the analysis due its greater polish resistance.

These curves can be used to roughly predict the average times required for friction values to fall to a value of 30. These estimates do not take into account either the total wheel passes or the amount of winter maintenance occurring on a given project, both of which may effect the rate of polishing. The models give the following average projections:

ADT	Time to Skid Number < 30
> 3000	15.6 years
< 3000	29.1 years

Table IV: 1990 Friction Values for Tined PCC Pavements with Limestone

Highway	MRM	Year Built	Date Tested	Skid Number	ADT	Trucks
14EB	232.38	1980	8/10/89	49.0	1281	143
14WB	232.38	1980	8/10/89	49.5	1281	143
14	233.94	1980	6/8/89	46.2	2429	255
14	239.73	1983	6/8/89	50.8	2430	255
14	246.63	1985	6/8/89	53.5	2511	283
16EB	49.69	1985	6/7/90	42.0	3519	345
16WB	49.69	1985	6/7/90	41.0	3335	334
18	0.00	1987	8/8/89	56.7	945	248
18	12.73	1983	8/8/89	52.5	2809	433
18	22.90	1984	8/8/89	56.3	1930	261
85	45.35	1986	7/11/89	47.5	5070	243
85	50.16	1986	7/11/89	44.5	4363	489
90EB	32.85	1983	5/22/90	46.9	5030	734
90EB	37.04	1981	5/22/90	38.0	4765	667

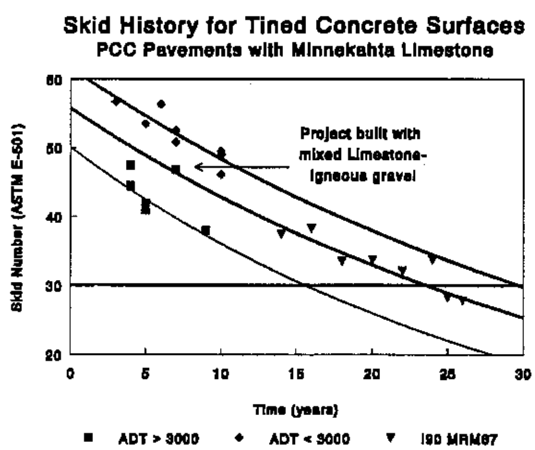

Figure 8: Skid History for Tined Pavements

Both values appear reasonable based on current project skid values especially considering that the stretch of I90 previously discussed (MRM 67-76) reached an average skid number of 30 after 23.6 years. These results imply that a pavement constructed using limestone coarse aggregate and with an expected ADT over 3000 will polish to an unacceptable condition long before its service life is exhausted.

The I90 project (MRM 32.85) where a mixed limestone-igneous gravel was used as an aggregate provides a partial solution to the rapid polishing problem on high ADT pavements. The presence of 20-30% hard gravel in the coarse aggregate slows the rate of polishing by about 25%. The projected age when this project will be down to a friction value of 30 is 22.7 years as compared to only 18 years for the adjacent limestone-only project (MRM 37.04). Addition of an appropriate percentage of suitably hard, nonreactive and durable local gravel to the coarse aggregate for high ADT concrete pavements should be able to slow the rate of polishing to a sufficient extent that the polishing would not become a serious problem until close to the end of the pavement's design life. An alternative would be to construct new pavement in two plastic concrete lifts in a manner very similar to the construction procedures used for mesh-dowel PCC pavements in the 1960s with a preponderance of a polish resistant aggregate in the top lift. The fine aggregate used in all concrete paving mixes should be a durable, primarily siliceous sand to insure maximum microtexture durability.

Transverse Grooving Skid Resistance

Both eastbound and westbound driving lanes of Interstate 90 (MRM 55-66) were transversely grooved in the late fall of 1988 and spring of 1989 to restore skid resistance and improve traction under rain and snow storm conditions. 0.1" wide grooves were cut 1" apart and ¼" deep across 10' of each lane. The initial average friction value of the freshly grooved pavement was 44.4, a significant improvement over the low skid resistance of 26 prior to the rehabilitation. Like the shot blasted test sections, the skid

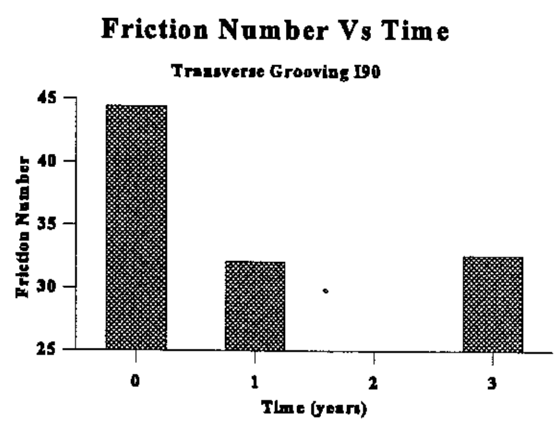

Figure 9: Transverse Grooving Friction Results

numbers dropped rapidly to an average value of 31.1 after one year as Figure 9 shows but surprisingly, at the end of three years the skid resistance remained stable at 31.6. Cutting grooves in the pavement surface will not necessarily reduce the rate of polishing of the concrete over time but it does appear to channel water so effectively that the skid resistance as measured by ASTM E501 will probably remain very close to 30 until the gradual wear eliminates the grooves. The initial increase in skid values was probably a transient effect of the residual microtexture generated from the sawing operations. Cutting a groove in polished pavement will not make that pavement less polished, but the rapid reduction in the surface water film provides a considerable improvement in safety. The bid price for this project was $1.35/yd^2$ for the grooving with a total cost of $1.49/yd^2$.

Rubberized Asphalt Chip Seal Test Section

Table V: Skid History of a RACS-Treated Test Section

Date Tested	Mileage Reference Marker	Skid Number
June 20, 1985	63.96	32
June 17, 1987	64.035 & 64.219	64.5
September 27, 1988	64.006 &64.171	57.5
July 13, 1989	64.095	56
May 24, 1990	64.074 &64.19	61.5
June 5, 1992	64.004	63

A ¼ mile stretch of eastbound I90 located just to the west of the shot blasting test sections (MRM 64.96) was treated with a rubberized asphalt chip seal (RACS) in July, 1986. RACS have been used on bridge decks as a combination membrane/skid resistant surface since the early 1980's. The extremely hard and angular quartzite chips used in the treatment provide high skid resistance for extended periods. The application of a RACS consists of brooming the concrete surface, applying the rubberized asphalt (25% ground rubber in 85-100 penetration grade asphalt) at a rate of 0.5 gallons/yd^2 and spreading ½" fractured quartzite chips at a coverage of 26-34 pounds/yd^2. Typical skid numbers immediately after application are in the mid-60 range or higher.

Skid resistance values for the RACS shown in Table V indicate that the chip seal maintains a high level of skid resistance over time. The high and low fluctuations in the skid numbers are a result of variables such as season (skid numbers obtained in the spring tend to be higher), wear on the skid tire and different operators. Although the RACS exhibits significant chip loss after 8 years under high traffic volume its skid resistance is still excellent. While the RACS provides a long term solution to inadequate skid resistance its use on concrete pavements may not be advisable. There is considerable evidence that RACS on bridge decks have created problems by changing the way moisture moves through the deck. Placing a RACS on a PCC pavement may result in an increase in moisture levels in the concrete as well as a tendency to retain moisture in the slab. The fine aggregate used in constructing the Interstate near Rapid City are mildly alkali-silica reactive (ASR) and moderate ASR cracking is evident in the pavement. Since ASR expansion is driven by the available moisture in the concrete the routine use of RACS to restore skid resistance could significantly accelerate the rate of deterioration of these pavements leading to a substantial reduction in their remaining service life.

Otherwise RACS are an economically attractive solution to insufficient skid resistance. The average cost for placing RACS on bridge decks using maintenance forces was $\$2.06/yd^2$ (1988-1991) which equates to $14,500/lane-mile of PCC. Although contract application of RACS would probably be somewhat higher, at least initially, the total cost would still be reasonable. Full width RACS should be considered as an alternative skid rehabilitation strategy on pavements which are programmed for replacement within the next few years. An alternative approach which may be extremely cost effective would be to apply the RACS only in the wheel paths or from wheel path edge to wheel path edge which would allow moisture transmission to remain relatively normal.

Skid Restoration of Flushed AC Pavement Chip Seals

The same Minnekahta limestone associated with polishing problems on PCC pavements is also prone to flushing and a subsequent reduction in skid resistance when used for chip sealing AC pavements, especially ones built using this limestone as the coarse aggregate. As an adjunct to the primary goal of this research project, a series of test sections were constructed using the Skidabrader to see if shot blasting is an effective means of restoring skid resistance. The first test section was established in the northbound driving lane on SD79 south of Rapid City at MRM 74 on October 3, 1989. This bituminous pavement was chip sealed in 1984 but flushing and rutting had coated the top surface of the chips to the point where the skid resistance had dropped to an average value of 27.8 in the 300' test section. After shot blasting at an average speed of 90 feet/minute, the skid resistance had been improved to 66.1. A retest the following morning gave a friction value of 62.7. The decay of this improvement is shown in Figure 10 for the first two years after treatment and follows the same exponential pattern seen previously. Unfortunately, the location of this test section near a municipal solid waste facility made obtaining meaningful longer term results difficult due to dirt and debris buildup from the dump traffic.

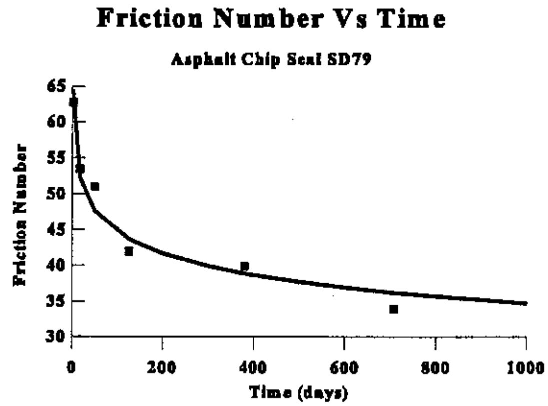

Figure 10: Skid Loss for AC Chip Seal

More extensive test sections were shot blasted in October, 1990 on both SD79 and US16 near Rapid City. A series of different Skidabrader speeds were used ranging from 60 to 110 feet per minute on the additional SD79 driving lane comprising 500' test sections (MRM 71.5-72.07) and the bulk of the test project (MRM 72.07-74.5) was shot blasted at 70 feet per minute, the lowest speed which did not dislodge chips from the pavement surface. The average friction value for this stretch of pavement prior to treatment was about 30. Figure 11 shows the friction values for the first three years after treatment, but the pavement was chip sealed again before further skid results could be obtained. An additional ¾ mile length of US16 that had been sealed in 1984 and had an average pre-treatment skid number of 31.5 was treated at this same speed and the average post-treatment friction value was 70. After three years the skid resistance had dropped to an

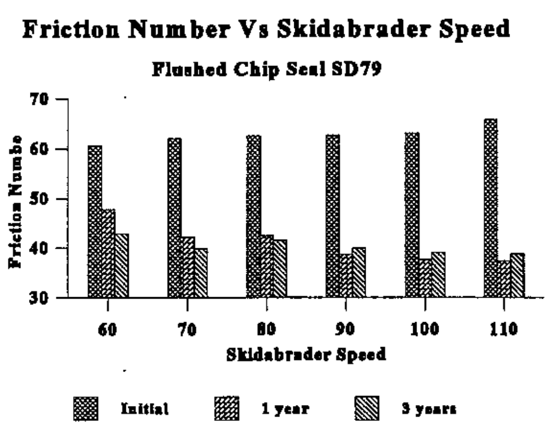

Figure 11: Friction Vs Skidabrader Speed

acceptable 43.1, but further monitoring of the skid loss over time was impossible due to the fact that this stretch of US16 was overlaid the following year.

The use of a Skidabrader for the purpose of restoring skid resistance to a flushed AC pavement appears to be a feasible method of achieving the equivalent of a new chip seal without having to redo the sealing process and risk worsening the flushing problem. This problem has been greatly increased in recent years due to the reduction in maximum chip size prompted by an increasing concern about windshield damage. The life expectancy of a new chip seal is only about six years, and even though the available data does not extend out this long, the benefit of using the Skidabrader to restore friction where flushing is a problem is significant. Frequently, attempts to reseal a flushed chip seal can result in the rapid onset of flushing on the new chip seal. Current cost estimates for this type of application range from \$.75-\$1.25/yd^2 depending on volume and production rate, which is considerably more expensive than the average cost of \$.51/yd^2 for informal contract maintenance chip sealing and comparable to the \$.71/yd^2 for regular contract chip sealing.

Conclusions

1. The Skidabrader shot blasting technique does not restore friction numbers as determined by ASTM E274 using a ribbed tire (ASTM E501) for more than six months on a PCC pavement containing Minnekahta limestone where diamond grinding was done previously. It does, however, appear to maintain friction values above 30 on previously untreated polished PCC pavement for 5 years or more.

2. The Skidabrader shot blasting technique appears to be a viable means of restoring hydroplaning resistance to polished PCC pavements where macrotexture is no longer available to channel water. The Skidabrader control parameters, (speed and impact energy) can be set to yield uniform and reproducible surface texture but these must be determined for each treated pavement.

3. Astroturf drag/tining does not appreciably slow the rate of polishing on PCC pavements containing susceptible aggregate. The degree of polishing over time is a function of time and traffic with limestone pavements having ADT >3000 vehicles per

day polishing to unacceptable skid values within 15-20 years and <3000 taking 30 years or more to reach the same point.

4. Transverse grooving is an extremely effective means of restoring hydroplaning resistance and generating a channeling macrotexture on a polished pavement. Unfortunately, transverse grooving does not restore skid numbers for a significant period of time but it does appear to be able to maintain values slightly above the acceptable threshold for 5 years or more.

5. The most effective means of restoring skid resistance is the rubberized asphalt chip seal which is capable of maintaining high skid resistance indefinitely. Although it is more expensive than any other method a partial RACS may solve this problem while allowing the pavement to transmit moisture normally.

6. The Skidabrader is capable of restoring acceptable skid resistance to a flushed AC chip seal for a period in excess of three years (possibly five years or more) and can be used as an alternative to resealing flushed pavements.

Recommendations

1. The Skidabrader should be approved as an alternate treatment to transverse grooving for skid restoration of polished PCC pavements if appropriate, with each treatment specifically optimized for the pavement being treated using sand patch, outflow and skid test results to set the operating parameters.

2. Astroturf drag and tining treatment should continue on all PCC pavements with the added assurance that the sand used in all concrete pavement mix designs is at least 30% siliceous material (as recommended by FHWA) to maximize microtexture life.

3. A series of test sections incorporating various amounts of a durable, non-polishing coarse aggregate mixed with limestone should be constructed on a high ADT section of pavement and its skid behavior monitored to determine an optimum mixture for long term skid performance. This research is already underway as project SD93-01,

Alternative Methods and/or Mix Designs for Constructing More Skid Resistant Limestone PCC Pavements.

4. A series of test sections using partial application patterns of rubberized asphalt chip seals (RACS) or other available systems (polymer chip seals) should be constructed on polished PCC pavements to determine the feasibility of developing an effective skid restoration process.

5. The Skidabrader should be allowed as an alternate to the following on flushed asphalt concrete pavements: chip sealing flushed AC pavements which have already been chip sealed with the treatment parameters determined on a project basis; mill and chip seal; polymer modified chip seal; construction of stone mastic asphalt (SMA) wearing course.