April 2009
Technical Memorandum: UCPRC-TM-2008-05

Friction Testing of Pavement Preservation Treatments: Temperature Corrections and Operator/Machine Variability

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Work Conducted Under the Program Friction Testing of Pavement Preservation Treatments, as part of Maintenance Task Order FY06/07

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DOCUMENT RETRIEVAL PAGE				Technical Memorandum No.: UCPRC-TM-2008-05
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Prepared for: California Department of Transportation Division of Research and Innovation Office of Roadway Research and Division of Maintenance Office of Pavement Preservation		**FHWA No.:** CA111200C	**Date Work Submitted:** July 20, 2009	**Memorandum Date:** April 2009
Strategic Plan Element No: Friction Testing of Pavement Preservation Treatments, Maintenance Task Order FY06/07	**Status:** Stage 6, final version		**Version No:** 1	

Abstract:

This technical memorandum describes work undertaken to establish an appropriate temperature correction equation for the British Pendulum Tester (BPT). The recommended correction equation was based on data collected in typical summer conditions in California and on previously constructed bituminous surfacings. The effects of different operators, instruments, levels of slider pad wear, and temperature were also studied in another experiment. No appreciable differences were found to be caused by the variables as long as the correct procedures were followed, the devices calibrated, and the surface temperature of the test pavement accounted for.

Keywords:

Friction, skid resistance, British Pendulum Tester, BPT, British Pendulum Number, BPN, variability, temperature correction

Proposals for implementation:

An improved equation, relating measured British Pendulum Number (BPN) at pavement surface temperature to BPN at 20°C, was developed from a series of tests conducted on pavements in Davis. This equation should be suitable for conditions experienced in California.

Results from different BPT instruments, operators, and levels of pad wear are comparable provided that the devices are calibrated and the BPT operators are trained in their correct use.

Related documents:

- Lu, Q. *Friction Testing of Pavement Preservation Treatments: Literature Review.* Technical Memorandum UCPRC-TM-2006-10. University of California Pavement Research Center, Davis, Calif., 2006.

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PROJECT OBJECTIVES

The Office of Pavement Preservation of the Division of Maintenance of the California Department of Transportation (Caltrans) has identified a need to establish a correlation between the California Skid Tester (CST) (CTM 342) and the British Pendulum Tester (BPT) (ASTM E303-93). The Division of Maintenance requested this correlation so that fog seals applied to roadways can be tested prior to opening to traffic to determine whether the pavement surfaces meet minimum friction requirements. If these requirements were not met, the contractor would be required to perform actions that would improve friction values to the required levels.

The first goal of this research is to develop, if possible, a correlation between friction values measured using CTM 342 and the BPT together with its level of significance. Such a relationship would be especially beneficial as it would permit utilization of the BPT to measure friction values right after application of a fog seal (because of the tester's ease of use) and conversion of those values, the British Pendulum Number (BPN), to a Skid Number (SN) required in the specification.

A second goal of the study is to investigate the change in friction resulting from the application of fog seals immediately before and soon after their application. Additional goals to be completed, if time and budget permit, are: (1) investigation of the change in friction from soon after fog seal applications and after two months of traffic; and (2) comparison of friction values obtained using the CST, the BPT, and the Dynamic Friction Tester (DFT).

This technical memorandum presents results of two research investigations associated with the first goal: (1) development of a new temperature correction relationship for the BPT to account for the significantly higher pavement temperatures experienced in California during BPT testing (up to 45°C); and (2) evaluation of the variability of the BPN resulting from different operators, BPT devices, slider pad wear, and pavement temperature.

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ABBREVIATIONS AND TERMS USED IN THE TEXT

AC	Asphalt concrete
BPT	British Pendulum Tester
BPN	British Pendulum Number
BPN_{20}	British Pendulum Number corrected to a standard temperature of 20°C
BPN_T	British Pendulum Number at test temperature T
TRL	Transport Research Laboratory(formerly British Road Research Laboratory [RRL])
T	Test temperature in degrees Celsius

1 INTRODUCTION

The Division of Maintenance (DOM) of the California Department of Transportation (Caltrans) has identified a need for a correlation between CTM 342 and the British Pendulum Tester (BPT) (ASTM E303-93). Accordingly, the DOM requested this correlation be established so that fog seals can be tested with the BPT prior to opening roadways to traffic to assess whether they meet minimum friction requirements. If that requirement is not met, the contractor would be required to perform actions that would improve surface friction to meet specification requirements.

This technical memorandum summarizes two studies: (1) development of appropriate BPN temperature correction factors for typical summer conditions in California; and, (2) development of variability and repeatability parameters based on the BPT results.

During 2006 and 2007, the University of California Pavement Research Center (UCPRC) used the BPT to measure the British Pendulum Number (BPN) on more than 70 flexible pavement surfaces around the state as part of Partnered Pavement Research Center Strategic Plan Element (PPRC SPE) 4.16, entitled “Investigation of Noise, Durability, Permeability and Friction Performance Trends for Asphaltic Pavement Surface Types.” The flexible pavement surfaces in the experiment design included these:

- Dense-graded hot-mix asphalt (HMA-D),
- Rubberized hot-mix asphalt, gap-graded (RHMA-G),
- Rubberized hot-mix asphalt, open-graded (RHMA-O),
- Conventional and polymer-modified open-graded hot-mix asphalt (HMA-O),
- Modified binder mix, gap-graded (MB-G),
- Modified binder mix, dense-graded (MB-D),
- Bonded wearing course (BWC), and
- F-mix (a type of open-graded mix used by the Oregon DOT).

The UCPRC used two BPT devices and several operators for the PPRC SPE 4.16 investigation. A preliminary study showed good repeatability between the devices and operators. This technical memorandum includes results of another and more comprehensive study of the variability of the data obtained with the BPT.

One of the limitations of the current ASTM method for the BPT is that it lacks any correction for temperature. The British standard for the BPT specifies a pavement surface temperature correction factor; however, this factor is applicable only for surface temperatures up to 35°C. The UCPRC has used the BPT at pavement surface temperatures up to about 50°C, which are not uncommon in California during the summer season. Accordingly, a new correction factor extended to higher temperatures has been developed and is included herein.

2 TEST PROCEDURES AND OPERATOR TRAINING

The UCPRC has developed a set of standard procedures for the BPT. The development and use of these procedures ensure that operators receive the same level of training and follow the same procedures in the field. The majority of the operational aspects of the BPT are prescribed by measurable parameters; e.g., length of slider in contact with the test surface and allowable amount of slider wear. One operational aspect considered subjective is the wetting of the test surface prior to releasing the pendulum. Accordingly, a specific methodology that has been introduced covers how the pavement surface is wetted immediately before the pendulum is released. The pavement surface is wetted with five sweeps of water sprayed from a hand-held pressurized spray bottle. This ensures that the same quantity of water is present on the surface for each pendulum swing.

3 TEMPERATURE CORRECTIONS

Previous research has identified that results from the BPT are dependent on the temperature of the pavement and rubber type when using natural rubber sliders (TRL sliders) *(1)*. The British standard (BS7976-2:2002) for the operation of pendulum testers includes a temperature correction factor for surface temperatures up to 35°C, whereas the ASTM standard (ASTM E 303-93) makes no provision for temperature correction. Pavement temperatures of up to 42°C had been measured during BPT testing for the Caltrans-funded UCPRC study on quiet pavements (SPE 4.16). This raised questions about the validity of using the correction factors given in the British standard at temperatures above that listed in the standard. Lu *(1)* summarized different temperature corrections that have been proposed by different researchers, as shown in Figure 3.1. Since the British standard only provides a correction for temperatures up to 35°C, and all of the other published correction factors appear to have been developed on laboratory prepared samples, it was decided to test a series of five sites at a range of temperatures from 20°C to 45°C.

These tests were performed in September 2006 by a single operator on pavements on the campus of the University of California, Davis, using the same BPT. Each site was tested over the span of one day, starting early in the morning and continuing until midafternoon, when the surface temperatures had peaked for the day. The measured data are shown in Figure 3.2. The data show a relatively consistent trend, with the BPN decreasing as the temperature increases. Bazlamit and Reza *(2)* in a study conducted at the University of Ohio determined that a one-degree increase in the surface temperature resulted in a 0.232 decrease in the BPN, as seen in Equation (1):

$$\Delta BPN = 0.232(T - 20) \quad \textbf{(1)}$$

where: ΔBPN = change in BPN number

T = measured temperature, °C (range: 0 to 40°C).

A linear regression was applied to the data to determine the rate of change of the BPN with increasing temperature for the UC Davis data; this would enable the form of the correction developed by the Ohio researchers to be used. It was assumed that the BPN measured at 20°C was the correct value and would not require correction for temperature. The resulting expression is shown in Equation (2):

$$\Delta BPN = 0.466(T - 20) \quad \textbf{(2)}$$

Note that the coefficient in Equation (2) is two times that determined by Bazlamit and Reza (0.466 versus 0.232).

Equation (2) was used to correct the data shown in Figure 3.2 and the adjusted values are shown in Figure 3.3. These data from each site appear to be relatively constant over the temperature range evaluated; however, the BPN values for each site exhibited differences as high as 6.

In another study, Oliver et al. *(3)* developed a temperature correction expression that was a function of both temperature and BPN, i.e.,

$$BPN_{20} = \frac{BPN_T}{1 - 0.00525 \times (T - 20)} \quad \textbf{(3)}$$

where

BPN_{20} = BPN number at 20°C

BPN_T = BPN number at T°C

This equation was applied to the five data sets, again assuming the measured value at 20°C required no correction for temperature.

$$BPN_{20} = \frac{BPN_T}{1 - \alpha(T - 20)} \quad \textbf{(4)}$$

For each data set, the value of α was determined and resulted in an average value of 0.00662 with a range varying from 0.00454 to 0.00803. This range bounded the value 0.00525 shown in Equation (3).

Given the wider range of BPN and temperatures from the Oliver study, a weighted average of the UCPRC and Oliver α values, using weighting factors of 0.67 and 0.33 respectively, was determined to be 0.00617. This was rounded to 0.0062 so that a greater accuracy than actually exists would not be implied by the additional digits. The adjusted data, tabulated in Appendix A, are plotted in Figure 3.4; these results are similar to those determined using the temperature-only correction expressed by Equation (2).

The data were also analyzed by forcing a linear relationship of the terms ($1-BPN_T/BPN_{20}$) versus ($T-20$) to pass through zero (which it should). The average slope for the resulting line was determined to be 0.0064 with a much lower R^2 value (four BPN values in the range 0.82–0.89 and one at 0.57). Accordingly, it was decided to use the form of Equation (4) with a value of α equal to 0.0062 as follows:

$$BPN_{20} = \frac{BPN_T}{1 - 0.0062 \times (T - 20)} \tag{5}$$

In addition it was decided that the correction should be applied to the individual measured BPN values (five readings per test spot) before the corrected values are averaged to give a single value for the test site. The floating point values for the individual measurements would be carried through to the averaging stage, at which point an integer value would be recorded as the temperature-corrected value.

From the results of this analysis, it would appear that the variation in data would be within ±3 BPN units for temperatures in the range of 20°C to 45°C.

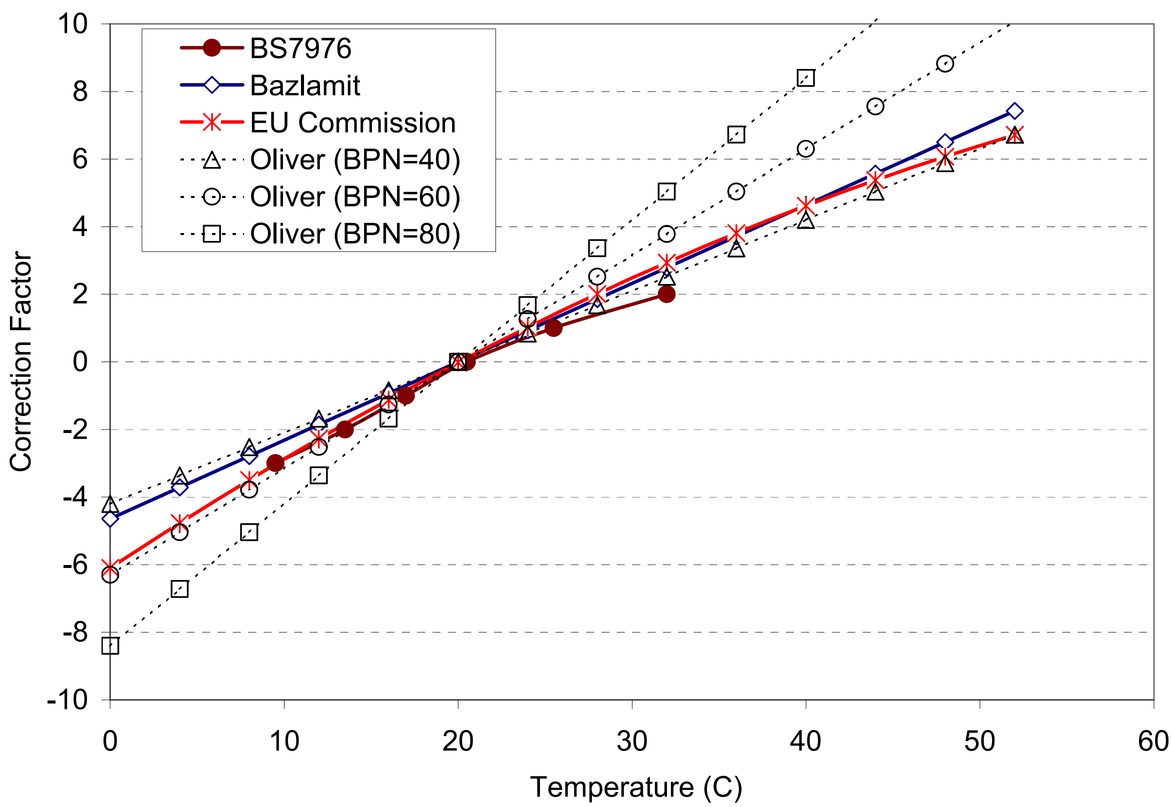

Figure 3.1: Various temperature correction factors for British Pendulum Numbers *(1).*

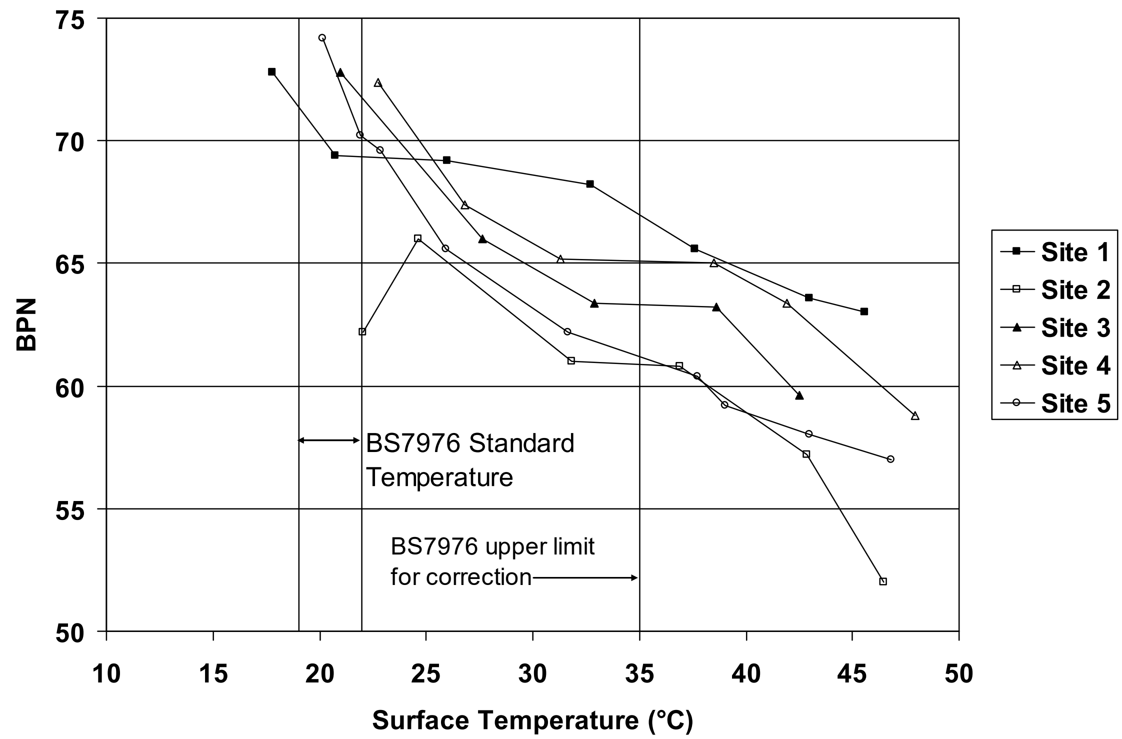

Figure 3.2: Uncorrected BPN data for the five sites.

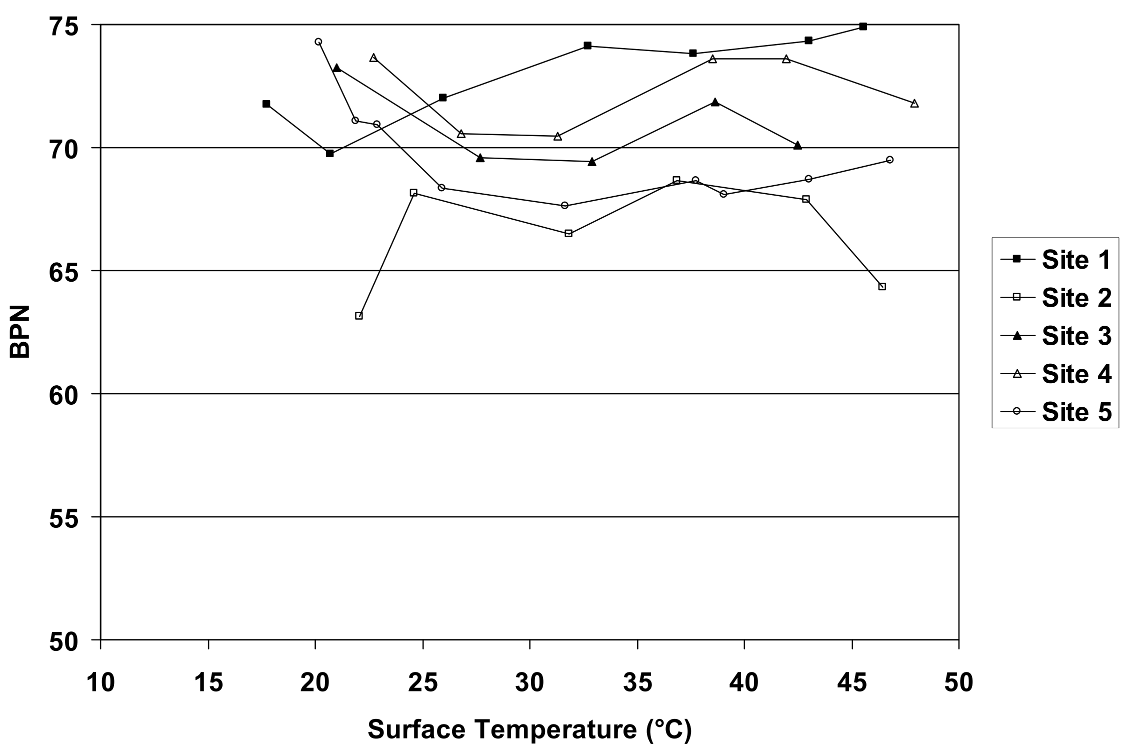

Figure 3.3: Corrected data using the linear UCPRC temperature correction.

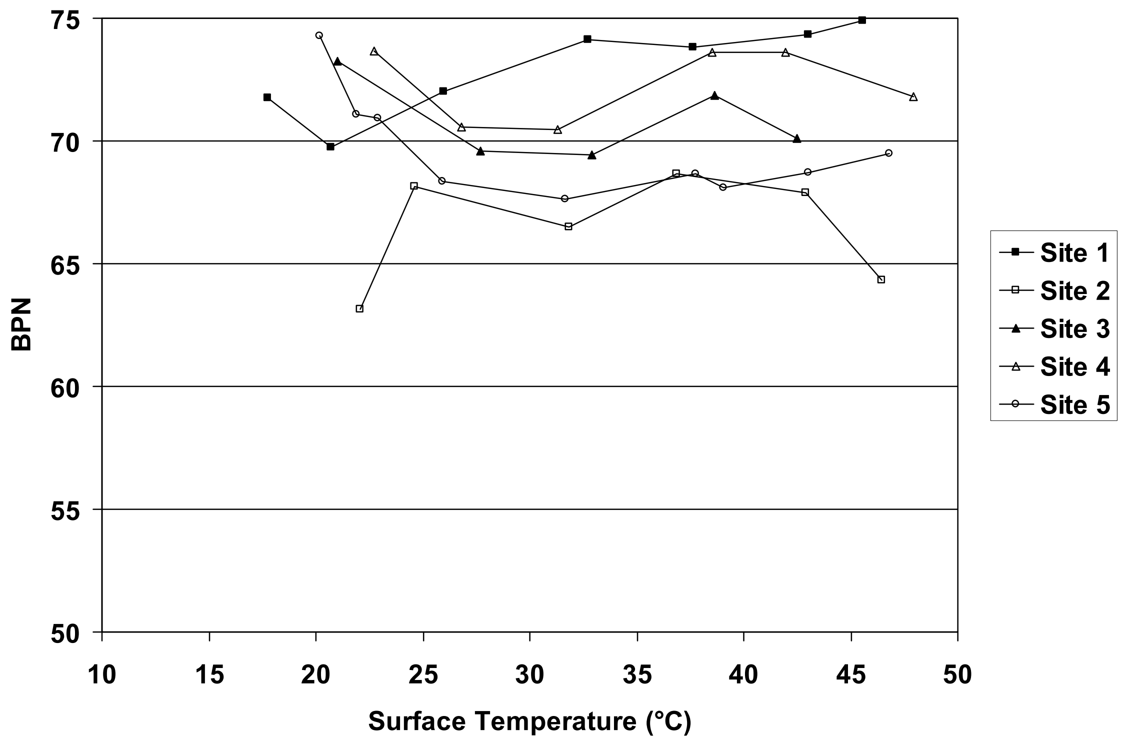

Figure 3.4: Corrected data using the UCPRC temperature/BPN correction.

4 EFFECT OF OPERATOR, INSTRUMENT, AND PAD WEAR ON BPN

This study was designed to test four variables affecting the results of the BPT and included the following:

1. Temperature (low and high),
2. Pad wear (new/slight and medium/heavy),
3. Two devices, and
4. Two operators

The goal of the study was to determine the sensitivity of the BPT to each of these variables. A factorial experiment consisting of two temperatures, two pad wear levels, two devices, and two users was conducted at 10 pavement sites in the city of Davis and on the campus the of University of California, resulting in 160 data points. The same procedure and sequence of test parameters was followed at each site to ensure as much consistency as possible. For example, the instrument was removed from the pavement and adjusted out of level before measuring the next equipment-operator combination. The operator for the next set of measurements was required to place the BPT on the seating pads (which were not removed during measurements at the same temperature), level the device, and set the contact length of the slider on the pavement prior to taking measurements. The zero reading of the device was checked several times during testing at each site.

To obtain the different test temperatures, the two sets of tests at each location were either tested early and later on the same day (two sites) or on different days (eight sites). To ensure a difference in the level of pad wear, new pads were placed on the slider when the current pad showed more than 2 mm of wear. The medium/heavy wear pads were removed from the test program when the level of wear reached 4 mm. A summary of the test locations is listed in Table 4.1. Four of the sites had an average temperature difference of five degrees or less. As a result of these small temperature differences, it was decided to remove temperature as a variable from the analysis and analyze the data as 20 sets rather than 10 sets. This would increase the population for the statistical analysis of the data. The four sites that had a small temperature difference would also be analyzed separately to look at the repeatability of the measurements.

For each set of unique measurements, the raw BPT data for each individual test was corrected for temperature using the correction factor developed earlier in Section 3 (Equation 5). After the application of the temperature correction, the BPN values were averaged to determine the BPN_{20} for each combination of instrument, operator, level of pad wear, and temperature. All of the analyses and reporting used integer values for the BPN. These BPN_{20} values for the 10 sites for one instrument-operator-pad wear-temperature combination are shown in Figure 4.1 with BPN_{20} values ranging from 53 to 73.

Table 4.1: Summary of Test Sites

Site No.	Location	Surface Type	Test Date 1	Surface Temperature 1 (°C)	Test Date 2	Surface Temperature 2 (°C)
1	UCD	New slurry seal	9/7/06	27.6	9/7/06	37.0
2	UCD	New HMA	9/7/06	34.1	9/8/06	22.8
3	UCD	Fog seal	9/7/06	33.5	9/8/06	20.1
4	UCD	Older HMA	9/8/06	25.3	9/20/06	19.0
5	UCD	Medium-age HMA	9/8/06	23.6	9/20/06	16.6
6	CoD	Slurry seal	9/19/06	19.9	9/19/06	38.1
7	CoD	Blue roller Hockey surface	9/19/06	21.8	9/20/06	24.3
8	CoD	Smooth HMA	9/19/06	22.4	9/20/06	21.9
9	CoD	Rough HMA	9/19/06	28.0	9/20/06	27.8
10	CoD	Smooth HMA	9/19/06	26.1	9/20/06	21.5

Note: UCD = University of California, Davis; CoD = city of Davis.

The datasets are identified by a three-letter code: *XYZ,* where *X* represented the operator and had a value of A or B, *Y* represented the instrument and had a value of C or D, and *Z* represented the level of slider pad wear and had a value of E (new pad) or F (moderately worn). Temperature-corrected BPN results used for the following analyses, shown in Figure 4.2 to Figure 4.5, are summarized in Appendix B.

4.1 Repeatability of Results

The four sites that had an average temperature difference of five degrees or less were Sites 7, 8, 9, and 10. The absolute difference between the BPN_{20} values for each unique test configuration was calculated, and the average difference was 3 BPN units. The standard deviation was 2.5 BPN units, and the 90th percentile value was 5 BPN units, that is, 90 percent of the differences (28 out of 32 values) were 5 BPN units or less.

The British standard specifies a range of ±5 BPN units when validating the BPT device on 3M 261X Imperial Lapping Film Grade 3MIC paper and a range of 5 BPN units when testing on smooth float glass. The ASTM standard specifies a standard deviation of 1.0 BPN units for the repeatability of each swing. It should be noted that all these limits are for a single test setup and not for the repeatability of the determination of a friction value. Slight variations in the instrument (leveling of the instrument and the length of the slider contact) between tests will also account for some variation. In addition, it was found that the temperature correction has a variation of ±3 BPN units (see Section 3).

Therefore it can be concluded that the repeatability of the results is ±3 BPN units when all the test conditions (operator, instrument, pad, and temperature) remain constant. This finding is based on test results that have been transformed to a standard test temperature of 20°C.

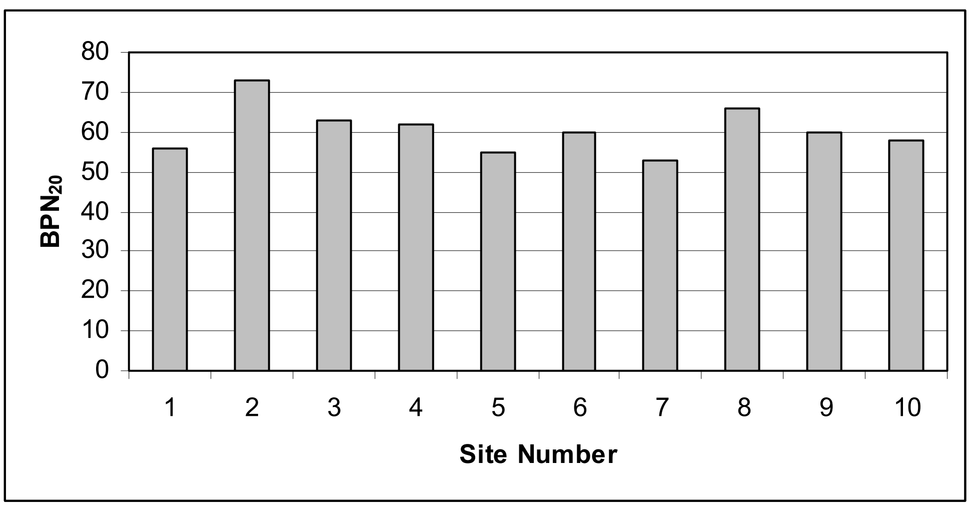

Figure 4.1: BPN_{20} values for each site (operator A, instrument C, pad wear E, temperature 1) from Table 4.1.

4.2 Effect of a Single Variable

To examine the effect of varying a single parameter, the dataset was paired in three different ways. For each pairing, one parameter was held constant and 80 data points were generated. For example, to examine the effect of the operator, the 80 data points were determined from the number of instruments (two) × the number of levels of pad wear (two) × the number of sites (10) × the number of temperatures (two): 2 × 2 × 10 × 2 = 80. This analysis was repeated two more times, the second time holding the instrument constant, and finally holding the level of pad wear constant. For each case the data were plotted on a scatter plot; the difference for each data pair was calculated; and the mean and standard deviation of the differences were determined.

The case of varying the operator is examined first. The results from the two operators are shown in Figure 4.2. (The figure also shows the line of equality and the boundaries of ±3 BPN_{20} units, which is the assumed inherent variability in the measurements.) The mean difference was 0.05 BPN_{20} units, showing that there is no appreciable operator bias in the measurements. The standard deviation of the differences was 2.2 BPN_{20} units.

The case of varying the instrument is examined next. The results from the two instruments are shown in Figure 4.3. (The figure also shows the line of equality and the boundaries of ±3 BPN_{20} units, which is the assumed inherent variability in the measurements.) The mean difference was 0.5 BPN_{20} units. This indicates that there exists a slight bias between the two instruments; on average, Instrument D gives slightly higher readings than Instrument C. The standard deviation of the differences was 3.2 BPN_{20} units. This finding indicates the need to ensure that the instruments are calibrated on a regular basis.

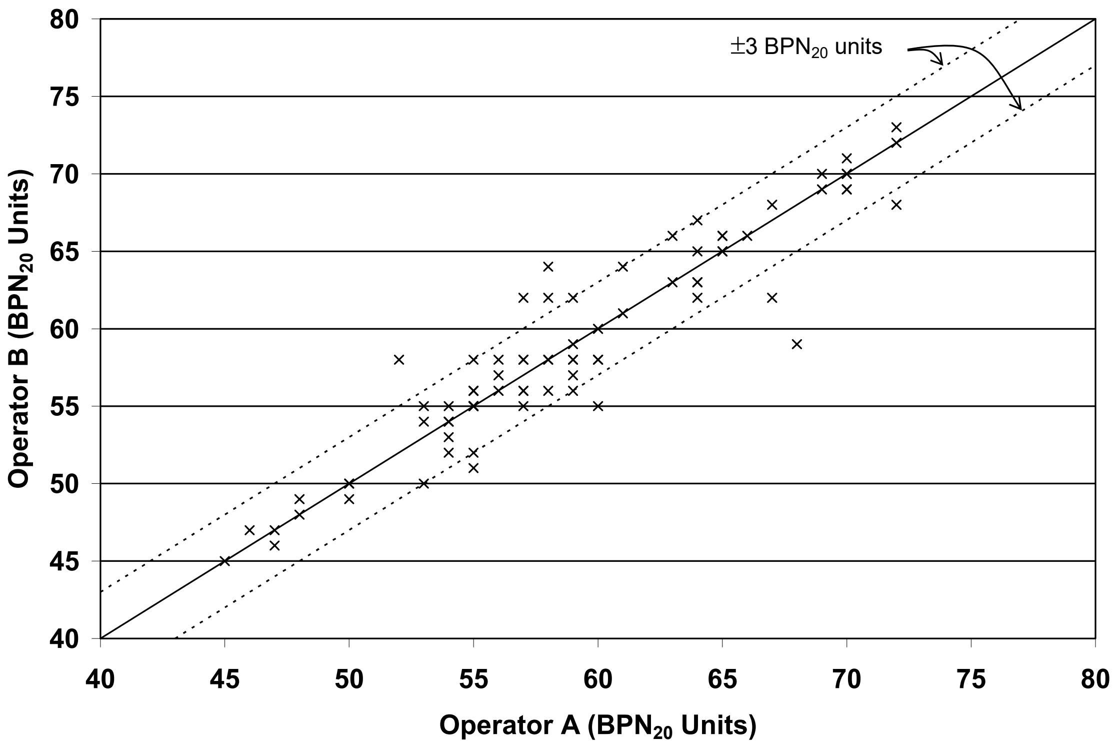

Figure 4.2: Effect of two different operators using the same instrument and level of pad wear.

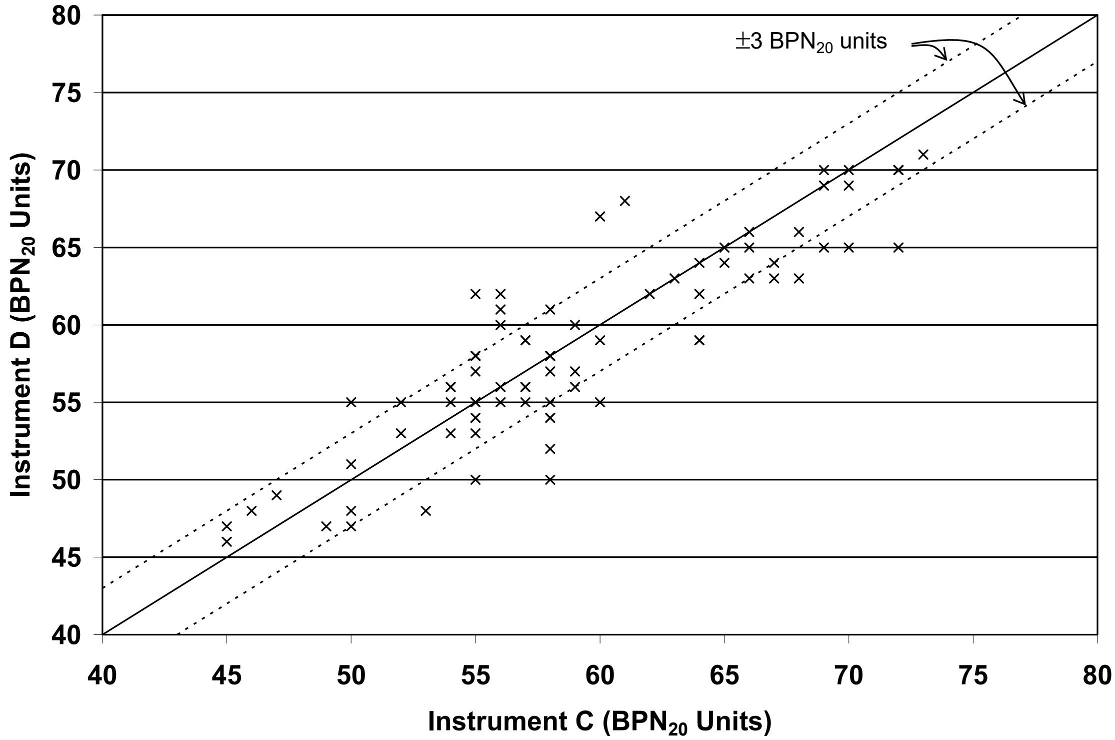

Figure 4.3: Effect of two different instruments with the same operator and level of pad wear.

The last case examined the level of pad wear. The results from the two levels of pad wear are shown in Figure 4.4. (The figure also shows the line of equality and the boundaries of ±3 BPN_{20} units, which is the assumed inherent variability in the measurements.) The mean difference was 0.05 BPN_{20} units, showing that there is no appreciable bias between the two levels of pad wear. The standard deviation of the differences was 2.7 BPN_{20} units. Fourteen of the 80 data points had a difference of greater than 3 BPN_{20} units.

4.3 Effect of Two Variables

To analyze the effect of using two variables, data pairs were created by comparing the operators when they were using different machines and different levels of pad wear. The results are shown in Figure 4.5. (The figure also shows the line of equality and the boundaries of ±3 BPN_{20} units, which is the assumed inherent variability in the measurements.) The mean difference was 0.05 BPN_{20} units, showing that there is no appreciable bias between operators using different instruments and differing levels of pad wear. The standard deviation of the differences was 3.2 BPN_{20} units.

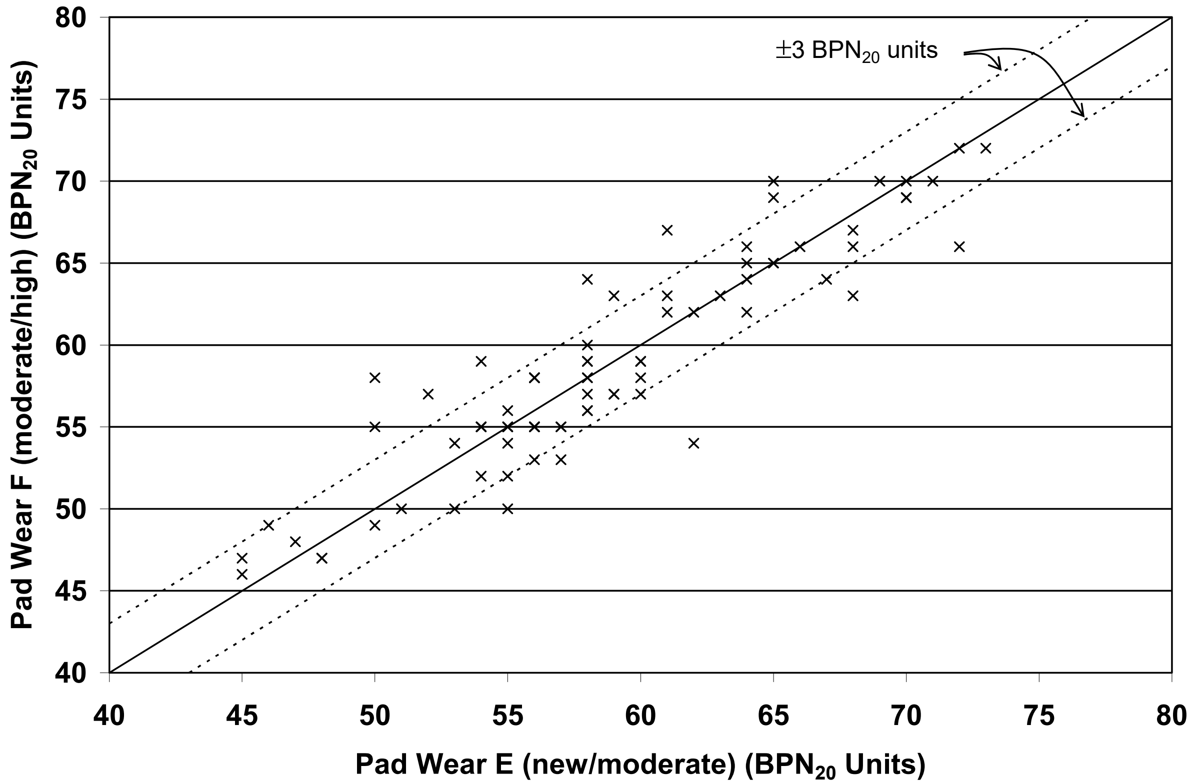

Figure 4.4: Effect of two levels of pad wear with the same operator and instrument.

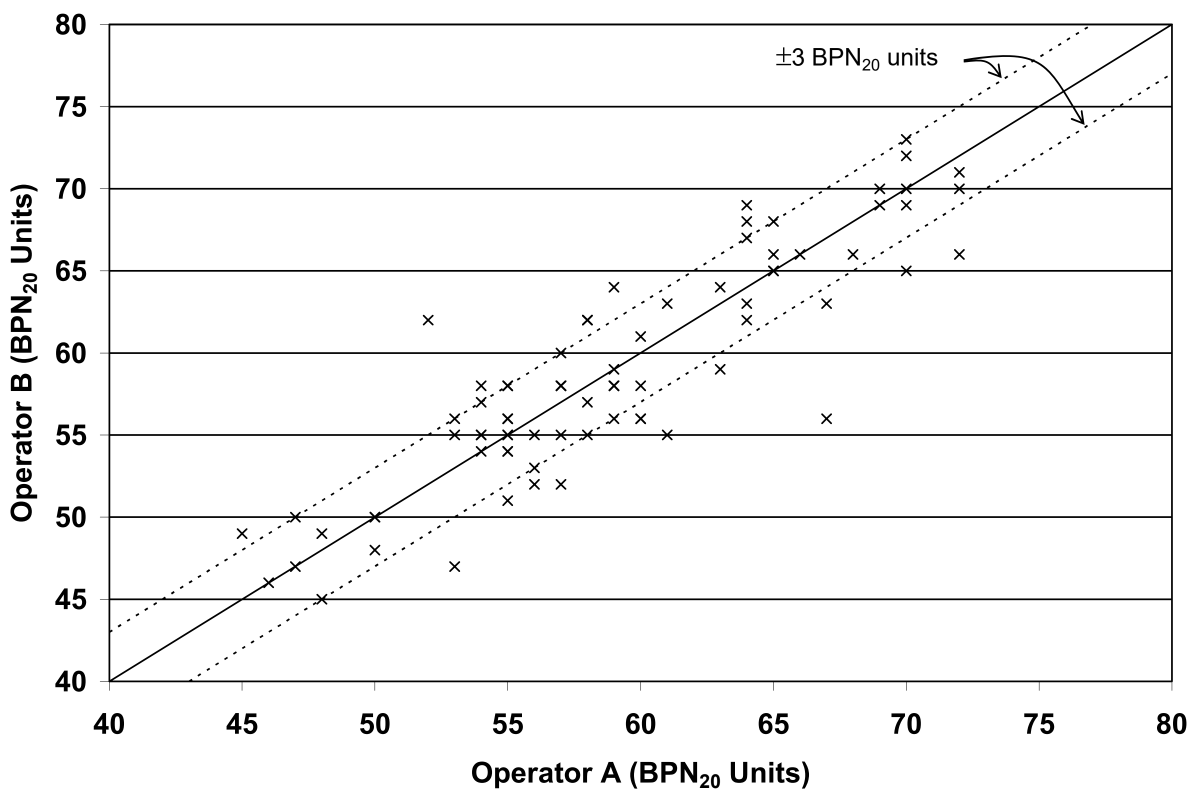

Figure 4.5: Effect of instrument and two levels of pad wear with the same operator.

5 SUMMARY AND CONCLUSIONS/RECOMMENDATIONS

5.1 Temperature Corrections

The British standard for British Pendulum Tester (BPT) measurements requires the use of a temperature correction factor for test temperatures outside the range of 17°C to 22°C; the ASTM standard does not specify a temperature correction. To examine the influence of temperatures on the British Pendulum Number (BPN), particularly at higher pavement temperatures representative of the conditions in some areas of California during the summer period, a study was initiated by evaluating correction factors developed in Great Britain, Ohio *(2),* and Australia *(3).* Corrections to the British standard encompass the range of 8°C to 35°C; which is exceeded in California by at least 10°C. Using this approach, computed corrections were insufficient to normalize the range of values measured by the UCPRC. Similarly, expressions developed by Bazlamit and Reza *(2)*, using a linear correction factor, were also found not to be large enough—as evidenced by the correction factor calculated using the UCPRC study data that was twice the value that Bazlamit and Reza determined. The expression for the correction factor developed by Oliver et al. *(3),* which included both the initial BPN value and the surface temperature, was adopted. However, it was necessary to modify the coefficient in this expression using the UCPRC data from the five sites study. After applying the new correction factor to the raw data, it was found that the inherent variability in the measured values was ±3 BPN_{20} units.

For future studies using the BPT test, this result should be useful in properly interpreting the test data obtained at different temperatures.

5.2 Measurement Variability

Based on the results presented in Section 4 of this memorandum, it can be concluded that there is no appreciable difference in the BPN_{20} results obtained by either suitably trained and experienced operators or the results obtained from slider pads that are within the material, age, and level-of-wear specifications. There was a small bias between the two instruments that were used; however, the bias was small (0.5 BPN_{20} units) and within the repeatability limits that were found in this investigation.

In order to obtain useful data with BPT, the results emphasize the importance of properly training for operators of this equipment. Also the importance of frequent calibration and proper equipment maintenance has been demonstrated.

5.3 Summary and Conclusions/Recommendations

Conclusions/recommendations from the results of the study include the following:

1. When using the BPT, temperature corrections are required for the measured BPN values, particularly at higher pavement temperatures. Equation (5) is recommended for use, i.e.,

$$BPN_{20} = \frac{BPN_T}{1 - 0.0062 \times (T - 20)} \quad \textbf{(5)}$$

where:

BPN_{20} = BPN number at 20°C

BPN_T = BPN number at T°C

2. So long as operators are properly trained and the BPT slider pads are within the material, age, and level-of-wear specifications, comparable BPN results can be obtained by different operators and use of more than a single BPT. This requires, however, frequent equipment calibration and maintenance.

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3. Oliver, J. W. H., P. F. Tredrea, and D. N. Pratt. *Seasonal Variation of Skid Resistance in Australia.* Australian Road Research Board, Melbourne, Vic., Australia, 1988.

APPENDIX A: TEMPERATURE CORRECTION DATA

Table A.1: Temperature Correction Data

Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		Site 7		Site 8		Site 9		Site 10	
ST	**BPN Corr**	**ST**	**BPN Corr**	**ST**	**BPN Corr**	**ST**	**BPN Corr**	**ST**	**BPN Corr**	**ST**	**BPN Corr**	**ST**	**BPN Corr**	**ST**	**BPN Corr**	**ST**	**BPN Corr**	**ST**	**BPN Corr**
24	56	22	73	19	72	19	59	16	61	19	58	21	53	21	70	26	60	21	57
27	59	22	71	19	65	19	57	16	61	20	60	21	48	22	71	26	60	21	55
27	65	22	71	19	68	19	60	16	61	20	59	21	50	22	71	27	63	21	58
28	55	23	74	19	66	19	59	17	60	20	59	22	51	22	70	27	70	21	58
28	60	23	73	20	66	19	56	17	67	20	57	22	50	22	65	27	54	22	57
29	56	23	72	20	66	19	58	17	63	20	58	22	49	22	70	27	65	22	56
29	61	23	71	22	66	19	60	17	65	20	59	22	48	22	66	28	61	22	56
29	57	24	74	23	67	19	58	17	58	20	56	23	48	22	71	28	57	22	59
35	55	33	73	32	67	23	59	21	55	37	61	23	46	22	70	28	64	25	59
35	55	33	70	33	63	24	58	23	55	38	61	24	46	22	70	28	59	26	58
36	61	33	70	33	70	25	57	23	56	38	63	24	48	22	66	28	61	26	57
37	56	33	74	33	64	25	58	24	55	38	62	24	48	22	71	28	58	26	57
38	62	34	70	33	67	26	62	24	54	38	59	24	47	22	66	29	60	26	57
38	56	34	69	34	70	26	57	24	55	38	63	25	47	22	70	29	65	26	58
38	65	36	74	35	64	26	57	24	56	38	62	25	50	23	66	30	63	27	56
39	58	37	70	35	68	27	59	26	57	40	62	25	51	24	67	30	61	27	55
ST	Surface Temperature																		
BPN	Temperature-corrected BPN																		

APPENDIX B: OPERATOR-DEVICE-PAD WEAR-VARIABILITY DATA

Table B.1: BPN Variability as a Function of Operator, Equipment, and Pad Wear

ACE	ACF	ADE	ADF	BCE	BCF	BDE	BDF		Legend	
55	52	57	53	56	58	62	54			
50	55	55	50	50	58	51	50		Operator: A, B	
67	64	64	64	68	67	63	63		Equipment: C, D	
72	72	70	70	73	72	71	70		Pad wear level: E, F	
58	64	58	59	64	62	62	62			
72	66	65	65	68	66	66	66			
60	57	55	55	58	56	55	56			
59	57	60	59	56	58	60	58			
54	55	53	54	54	55	55	55			
61	63	68	63	64	66	59	63			
60	59	59	57	58	59	58	56			
54	55	56	55	54	52	56	55			
53	50	48	47	50	49	48	47			
45	46	47	48	45	47	46	49			
65	70	64	65	65	69	65	65			
70	69	69	70	70	69	70	69			
58	57	54	59	58	58	52	57			
58	60	61	67	56	55	61	62			
56	55	55	54	57	55	56	53			
57	55	56	58	55	55	58	58			