# ASSESSING ROAD SURFACE FRICTION WITH THE BRITISH PENDULUM TESTER, IN NEW ZEALAND

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## AN IMPORTANT NOTE FOR THE READER

The research detailed in this report was commissioned by Transit New Zealand when it had responsibility for funding roading in New Zealand. This funding is now the responsibility of Transfund New Zealand.



*The material contained in this report is the output of research and should not be construed in any way as policy adopted by Transit New Zealand or Transfund New Zealand but may form the basis of future policy.*

# CONTENTS

# EXECUTIVE SUMMARY

## Introduction

The British Pendulum Tester (BPT) is an instrument commonly used in New Zealand to assess the skid resistance of road surfaces. The instrument has a rigid swinging arm approximately 450 mm long with a spring-loaded rubber slider of approximately 75 x 20 mm area. The slider contacts the road surface at a speed of about 2 m/s. The swing measures the frictional resistance between the rubber slider and the road surface, and its characteristics are considered to simulate sliding between a vehicle tyre and a road surface for speeds of about 50 km/hour. The units of measurement are called British Pendulum Numbers (BPN).

However, the concern is that using a BPT, particularly on the larger sized sealing chip, the following problems may significantly affect repeatability and reproducibility of BPT measurements:

- difficulty in seating the instrument firmly on the road surface;
- difficulty in accurately adjusting the slider contact distance on a surface having larger sealing chips;
- kick back and bucking of the instrument as the slider contacts these larger chips during testing.

## Phases of Investigation

The investigation of the repeatability and reproducibility of the BPT, and of the influence of test surface parameters, was carried out in four phases over a period of 30 months, from May 1992 to November 1994.

- **Phase 1 Inter-laboratory comparisons**

An inter-laboratory comparison was carried out, following the procedures of the standard ASTM E691-92, to establish the repeatability and reproducibility of the instrument. The substrates used in this phase were simulated road surfaces of sealing chip adhered to plywood backing to form test panels.

- **Phase 2 Influence of chip attributes**

To determine the possible existence of any sustained relationship between chip source, chip size, BPN and repeatability, a single laboratory conducted measurements on additional test panels made with sealing chip from three other sources.

- **Phase 3 Effect of operator training**

Two operators were trained to employ identical test procedures and to minimise permitted variations, in an attempt to produce statistically identical results. Although it was principally to enable the fourth phase to be carried out, this phase also provided indications of approaches to reduce the wide repeatability and reproducibility found in Phase 1.

- **Phase 4 Road surface assessment**

The assessment of road surfaces in terms of skid resistance variation patterns (as determined by BPN) was examined over 12 road segments, each 50 m in length. For each road surface type, one of the sites was located on a curve, and the BPN measured along the wheeltrack in the direction of traffic movement were compared with those measured along the radial axis of the curve.

**Conclusions**

- The study has confirmed that wide margins of repeatability and reproducibility of measurements occur when using the BPT instrument on most New Zealand road pavement surfaces.

  The pattern is for good repeatability (4-8 BPN) for measurements on asphaltic concrete and friction course; moderate repeatability (10-11 BPN) on fine chipseal surfaces (grade 6); and poor repeatability (16-34 BPN) on larger chipseal surfaces (grades 2-4).

  This pattern was sustained in general for material from four quarries, but with some variation for individual quarries.

  The pattern of BPN rising to a maximum for grade 4 chip and declining for chip sizes both larger and smaller, that had been found for one quarry, was not sustained for material from the three other quarries.

- Reproducibility is always poor, being 20-35 BPN for all surfaces tested.

- The poor repeatability would appear to arise from a combination of:

  - the relatively small size of the area sampled by the instrument compared to the irregular nature of the surface;
  - the irregular surface, making placement of the instrument and setup of the contact distance difficult; and
  - the need for additional operator refinements.

- Once set up, the BPT can quickly give a stable measurement between successive swings on most occasions.

  Occasionally many swings are needed for a valid measure and this appears to arise from the irregular surface making setup difficult or making the slider twist out of plane during tests.

- The study shows evidence of systematic error between laboratories and that some laboratories do not follow, in full, the measurement method used as a standard (described in TRRL Roadnote 27 (1969)), particularly for the required number of swings.

The large repeatabilities obtained on most chipseals, however, mean that steps to reduce these systematic errors will reduce reproducibilities only by about 10-25%. Further improvement will only be possible if repeatability is improved.

- The training of two operators at one laboratory so that they both used identical steps in the measurement method appeared to give significantly improved repeatability and, if this approach was conducted with other operators, substantial improvements in reproducibility may be obtained.

- The technique detailed in the standard ASTM E770-80, of closely examining the road surface and ascribing parameters to the sealing chip macro- and microtexture, appeared to be an effective method for understanding the nature of a road surface. However, although an equation linking these ASTM E770-80 parameters to measured BPN was derived, the significance of this relationship was that of an indicative trend only.

- Detailed measurements on the road segment showed that a road surface could be clearly separated into trafficked and untrafficked areas, i.e. wheelpaths and shoulders.

  Over a 50 m segment the BPN appeared to fluctuate randomly within a range of BPN values. This range was relatively narrow (5-6 BPN) for smooth surfaces such as asphalt, but widens for increasing texture size, as follows:

| Road surface | BPN range |
|---|---|
| Asphalt | 5-6 |
| Friction course | 9-10 |
| Grade 5 chipseal | 11-12 |
| Grade 3 chipseal | 13-14 |

- On curves the BPN is less in a radial direction than in the longitudinal direction, i.e. along the wheelpath of the traffic. This reduction in BPN is statistically significant but only to a moderate level of confidence. The BPN is often, though not always, lowest in the wheelpath closest to the centreline.

**Recommendation**

- Further work, if undertaken, could seek to improve both repeatability and reproducibility by training operators and by providing methods to ensure that the instrument is accurately adjusted.

# ABSTRACT

The British Pendulum Tester (BPT) is used to assess the skid resistance of road surfaces. There are concerns that on chipseal surfaces the instrument may not deliver accurate or consistent results, recorded as British Pendulum Numbers (BPN). As a result, a study was carried out between 1992 and 1994, over a 30 month period, in four phases.

Phase 1 established, by means of an inter-laboratory comparison, that measurements of chipseal surfaces had large repeatabilities and reproducibilities. This phase was carried out on test panels simulating road surfaces.

Phase 2, after testing more panels made from three grades of chip each selected from four quarries, could establish no consistent relationship between BPN, chip source or chip size. However, an indicative relationship could be established between BPN and the micro- and macrotexture of the chips as quantified by the methods of the standard ASTM E770-80.

Phase 3 involved training two operators to employ an identical test procedure, and for both operators to minimise permitted variations in procedure. Repeatabilities and reproducibilities for these two operators were found to be significantly improved than those found in the first phase of the work.

Phase 4 examined the pattern of variation of skid resistance (measured by the BPT) over road surfaces so that an appropriate sampling pattern could be proposed. A statistically significant pattern was found that showed: consistency of BPN over a 50 m length of road; lower BPN in the wheeltracks compared to the shoulders and between wheeltracks; and, on some curves, differences in the BPN measured in a radial direction compared to BPN measured longitudinally, i.e. in the direction of traffic.

# 1. INTRODUCTION

## 1.1 Description of Instrument

The British Pendulum Tester (BPT) is an instrument commonly used in New Zealand to assess the skid resistance of road surfaces. The instrument has a rigid swinging arm approximately 450 mm long, the end of which contacts the road surface with a spring-loaded rubber slider of approximately 75 x 20 mm area. The contact distance of the rubber slider with the test surface is set between 123 mm and 127 mm.

The energy loss caused by this contact results in a reduced upward swing. The extent of this upward swing is recorded on a scale of 0 to 140, the units of which are described as British Pendulum Numbers (BPN). This measurement can be used as a measure of frictional resistance between the rubber slider and the road surface. The instrument's characteristics are considered to simulate sliding between a vehicle tyre and a road surface for speeds of about 50 km/hour.

## 1.2 Background

The repeatability of the BPT has been assessed, as detailed in the Appendix to ASTM E303-93, *Surface Frictional Properties Using the British Pendulum Tester* (ASTM[1] 1993), and has been found to agree within one BPN.

However, within New Zealand the concerns are that, particularly on the larger sized sealing chips such as grades 2 and 3 chip, one or more factors may affect the repeatabilities and reproducibilities of the BPT. These factors are:

- difficulty in seating the instrument firmly on the road surface;
- difficulty in accurately adjusting the slider contact distance, on a surface having larger sealing chips;
- kick back and bucking of the instrument as the slider contacts these larger chips.

If these problems do occur, they may significantly affect the consistency of the results obtained from the instrument. Lack of consistency would be manifest as large repeatabilities and reproducibilities of the measurements. The possibility that repeatabilities and reproducibilities were large was investigated by undertaking an inter-laboratory comparison of the instrument.

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[1] ASTM American Society for Testing Materials

## 1.3 Duration of Project

This project was undertaken over a period of approximately 30 months, from May 1992 to November 1994, and consisted of four phases which were undertaken sequentially. Phases 2 and 4 were undertaken to resolve issues raised by phases 1 and 3. The phases were:

1. Inter-laboratory comparison;
2. Influence of chip attributes;
3. Effect of operator training; and
4. Road surface assessment.

Definitions of some of the technical terms used in this report are in Section 1.5 of this report.

## 1.4 Study Phases

**Phase 1: Inter-Laboratory Comparison**
Eight laboratories participated in the study. Because they were located throughout New Zealand, a group of easily transported test panels, made up with sealing chip to simulate typical New Zealand road surfaces, were prepared and used as substrates in the inter-laboratory comparison.

**Phase 2: Influence of Chip Attributes**
A pattern emerged from the inter-laboratory comparison, in which a relationship between BPN and sealing chip size was indicated. It showed that from grade 2 chip the BPN rose to a maximum at grade 4, then decreased to a minimum at grade 6 chip. As the chip for Phase 1 had been all from one quarry source, the strength of this relationship was investigated by:

- making up BPT test panels using chip from a wider range of quarry sources;
- visual examination using the methods of ASTM E770-80 (ASTM 1980) to examine the characteristics of the simulated road surface of the panels and the chip microtexture;
- a regression analysis of the parameters to explore possible relationships with the BPN.

**Phase 3: Effect of Operator Training**
Steps in the methodology that had not been written into the test methods set out as a standard in TRRL Roadnote 27 (TRRL 1969) were investigated in this phase. They are steps that can be influenced by the training and experience of the operator, and the sum of their effects can have an important bearing on the test results. These steps are:

- Setting the contact distance of the slider: setting the distance on either the inner limit (123 mm) or the outer limit (127 mm) of the instrument could give a variation of about 3 to 6 BPN;

- Setting the pressure of the slider when setting the contact distance: setting the distance either as a "firm" or a "soft" contact (a soft contact involves slowly touching the test surface with the pendulum foot) could give a variation of about 4 BPN;

- Returning the main axis of the slider to a position perpendicular to the plane of swing after the previous swing: large chips can twist the foot out of plane on the previous swing and wide variations in successive readings are often obtained;

- Influence of wind: a moderate wind following in the direction of the swing could occasionally cause a difference of about 4 BPN in reading, compared to the BPN obtained if the swing is against the wind.

A single operator could obtain more consistent readings, and two operators using the same instrument could attain a much better level of reproducibility (compared to those of the inter-laboratory comparison) if the test method incorporated systems for carrying out these four steps. If the reproducibility of two operators using the same instrument was close to the repeatability of one operator using that instrument, then it would be possible to interchange those operators.

Using two operators is desirable when making a large number of measurements because of operator fatigue and because two operators (one for traffic control) are usually present in most road assessment situations.

A close match between single operator repeatability and two operator reproducibility with a single instrument has further implications. BPT are subjected to periodic calibration and adjustment against a reference instrument. Therefore if reproducibility with two operators can be improved and instruments can be calibrated, then it could be possible to improve on the large reproducibilities found for phase 1 of this study.

**Phase 4: Road Surface Assessment**

The first three phases of this study have identified uncertainties in the results provided by the BPT used on a uniform surface. An additional variation occurring in road surface assessments is that trafficking can reduce the skid resistance of a road surface by wearing away the microtexture of the sealing chips. Accordingly, phase 4 of the study sought to establish how to assess skid resistance of segments of road surfaces, each approximately 50 m in length. Such matters were considered as:

- how many measurements were required for a statistically valid result;
- where these measurements should be located; and subsequently
- proposing an appropriate sampling methodology.

This fourth phase examined variations in skid resistance over the road segments, such as difference in skid resistance between inner and outer wheeltracks, on curves, and differences between the radial and longitudinal direction of traffic movement.

## 1.5 Definitions

- **Repeatability** of a measurement is the maximum difference in results that could be expected to occur between two tests performed by the *same* operator on the *same* surface 19 times out of 20 (i.e. to a 95% confidence level).

- **Reproducibility** of a measurement is the maximum difference in results that could be expected to occur for two tests performed by *different* operators on the *same* surface 19 times out of 20.

  Repeatability and reproducibility can then be used to relate a single measurement to the true value. For example, when an operator performs a single test on a surface, it can be assumed with 95% confidence that the true value of the BPN lies within a range defined by ±[(reproducibility)/√2] of the measured value.

- **Grade** is a system by which road surface chips (aggregates) are classified. This grading system is related to aggregate chip size and shape, with grade 2 being the largest and grade 6 being the smallest size.

- **Pendulum Number** is the value of skid resistance as indicated by the pointer and scale arrangement of the BPT. This value is also referred to as the BPN. The skid resistance of the surface tested can therefore be expressed in terms of the BPN, which increases as the frictional resistance between the surface under test and the rubber slider of the instrument increases.

## 1.6 Objectives

1. The first objective of the study was to assess the repeatabilities and reproducibilities of the results obtained from the BPT, when used to measure the BPN of typical New Zealand road surfaces.

2. The second objective was to establish possible relationships between the BPN and the attributes of the chips used in chipseals.

3. The third objective was to determine whether operator training could improve repeatabilities or reproducibilities.

4. The fourth objective was to develop a road assessment methodology by which the skid resistance, as indicated by the BPN, of a segment of road surface could be assessed.

# 2. PROCEDURES

## 2.1 Inter-Laboratory Comparison

To enable an inter-laboratory comparison to be undertaken on common surfaces, test panels that approximate typical road surfaces were made by adhering road sealing chip to plywood panels. These panels were then sent to participating laboratories throughout New Zealand to measure BPN using their calibrated BPT instruments, and these measurements were subsequently analysed using the procedures of ASTM E691-92 (ASTM 1992).

### 2.1.1 Testing Laboratories

Eight laboratories or testing agencies, listed below, were selected:

Works Consultancy branch laboratories at:

- Whangarei
- Auckland
- Nelson
- Christchurch
- Timaru
- Dunedin
- Works Central Laboratories, Lower Hutt

Ministry of Transport Road and Traffic Standards Section, Wellington.

These eight laboratories were selected for the following reasons:

- To obtain statistically valid comparisons;
- To have an even spread of laboratories throughout New Zealand;
- The laboratory routinely used the BPT instrument;
- The instrument had been calibrated within the previous 30 months.

### 2.1.2 Preparation of Test Panels

When sealing chips are initially placed and rolled during normal sealing operations they are arranged in an apparently random orientation. However, after several months' trafficking, the chips appear to become re-oriented into a tighter, mechanically interlocking matrix, with most having their average greatest dimension (AGD) as a base, and the average least dimension (ALD) as their vertical height.

This interlocking chip was reproduced using the grade 2 chip, hand placed into the interlocked structure, as one of the samples. Grade 2 chip, the largest chip size, was chosen because it has the greatest difference in texture between random placement and the final interlocking structure. The other samples were prepared using light rolling, enough to randomly tip many chips onto their AGD but not enough to cause interlocking.

Test panels were made up of the following eight surface types:

1. Mix 10 asphaltic concrete
2. Grade 2 chip, hand-placed on their average greatest dimension, interlocked with surrounding chips
3. Grade 2 chip, randomly distributed
4. Grade 3 chip, randomly distributed
5. Grade 4 chip, randomly distributed
6. Grade 5 chip, randomly distributed
7. Grade 6 chip, randomly distributed
8. Friction course

The sealing chip was obtained from Wellington City Council's Kiwi Point Quarry. The Kiwi Point chip is a greywacke material produced by crushing then graded by screening. This chip was washed and oven-dried, then adhered to the panels using a two-part non-slump epoxy adhesive.

The base for each test panel was a 550 x 500 mm rectangle of 9 mm marine plywood. This size was large enough for the BPT to be completely seated on the surface being tested, in a fashion similar to an actual test on a road. The size restricted the choice of measurement position so that, for repeat testing, the areas contacted by the foot of the instrument in separate tests tended to partially overlap each other.

For the hand-placed interlocking grade 2 chip, the adhesive was spread evenly across the panel to a depth of 3-4 mm using a notched trowel, and each chip was worked into this adhesive by hand, interlocking with the previously placed chip and using its average greatest dimension (AGD) as its base.

For the randomly distributed chip, of grades 2 to 6, the adhesive was spread across the plywood panel as described above, except that the depth of the epoxy was reduced for finer chip sizes. The chip was sprinkled onto this adhesive from a tray until overlapping occurred. Excess chip was removed by tilting the panel, and the remaining chip was worked into the epoxy, initially by hand, and then by very light pressure using a 70 mm-wide paint roller with the absorbent sleeve removed. This technique appeared to arrange the chip in a similar way to that achieved on a full-sized sealing project prior to the interlocking of the chip, caused by trafficking.

The mix 10 asphaltic concrete sample was formed by placing the asphaltic concrete on a plywood rectangle and compacting it using a vibrating hammer to a depth of 30 mm, level with 40-mm high timber sidings fitted to the panel edges.

The friction course sample was similarly prepared using a vibrating hammer, within 40 mm-high timber sidings fitted to the plywood panel edges.

### 2.1.3 Measuring BPN on Test Panels

A separate test sequence for testing the eight panels was determined for each laboratory using random numbers.

Each test surface was tested twice in a random order, thus obtaining 16 results from the eight panels at each of the laboratories. In the occasional case where the random numbers determined that a panel be tested twice consecutively, the BPT was to be removed from the panel, replaced, re-levelled and re-zeroed before the second test.

The relevant sections of TRRL Roadnote 27 (1969) were supplied to each laboratory as a guide for the requirements of the results so obtained, the number of pendulum swings over the surface required, acceptable differences between consecutive results, and other steps.

Instructions stressed that each repeat test of the panel should be treated as a new test and that no reference to the previous test results should be made, to avoid any operator tendency to re-adjust the instrument and the slider contact parameters to give closer agreement with previous measurements.

### 2.1.4 Operator

The person most familiar with the operation of the BPT at each of the eight laboratories was the person who carried out the skid resistance measurements by BPT of the test panels.

Although the relevant section of TRRL Roadnote 27 (1969) was attached to the instructions sent to each laboratory, a deliberate choice was that each operator conducted the tests according to the method commonly used at that laboratory, whether it was that as described by TRRL Roadnote 27 or variations thereof. This was to help identify systematic errors which may be occurring between laboratories, and also to provide a benchmark against which measurements made up to that time by the separate laboratories could be compared.

## 2.2 Influence of Chip Attributes

To investigate the relationship of chip size and other surface parameters to BPN, further test panels similar to those described in Section 2.1 of this report were made up using the chip from three other source quarries. The BPN was measured by Works Central Laboratories only, and surface parameters were measured using the techniques of ASTM E770-80 (ASTM 1980). All the BPN results were analysed for repeatability, and various relationships between BPN and surface parameters were examined.

### 2.2.1 Chip Sources

The chips used to make the additional test panels for phase 2 were sourced from the following quarries:

- Winstone's Quarry, Wellington
- Palmer's Quarry, Dunedin
- Winstone's (Lunn Avenue) Quarry, Auckland

In choosing these different sources an attempt was made to obtain chip of technically identical grading that was geologically different.

**Winstone's Wellington** quarry produces chip from a similar class of greywacke as that at Kiwi Point, but its crushing plant appears to be significantly different to that of Kiwi Point. It produces a chip that appears to be more angular, with more broken faces.

**Palmer's Dunedin** quarry produces chip from a blue/grey basalt. On initial observation, this material appears to be more angular than the Wellington greywacke chip. Some trouble has been experienced in the past with Palmer's chip polishing readily when trafficked, and consequently having reduced skid resistance.

**Winstone's (Lunn Avenue) Auckland** quarry produces chip from a volcanic basalt. This chip appears to have significantly harsher surfaces than the other chip in this study. It is used extensively in chipseals around the Auckland region.

### 2.2.2 Test Panels

Test panels of the additional chip materials were made up as described in Section 2.1 of this report. For the study, panels of test surfaces of grades 3, 4 and 6 chip were considered to be sufficiently representative of the variation that could be expected from the four different quarry sources.

### 2.2.3 Measuring BPN on Test Panels

Each test surface panel was tested for skid resistance in accordance with the TRRL Roadnote 27 (1969) method. For each surface, this test was conducted 10 times. Before each repeat test, the BPT was removed from the surface, replaced, re-levelled and re-zeroed. The tests on these surfaces were all carried out at Works Central Laboratories by the one operator.

### 2.2.4 Classification of Surfaces of Test Panels

ASTM E770-80, *Standard Test Method for Classifying Pavement Surface Textures,* (ASTM 1980) uses photographic techniques based on stereo photography and stereo microscopy to study road surfaces. This technique was followed but with variations appropriate for the direct examination of a sample of the pavement surface type. These variations were:

- A grid of 10 mm squares was marked off on a transparent sheet, as described in ASTM E770-80. From this, ten pre-determined, numbered, random squares were cut out. The grid was placed on the test panels of the sample surfaces, and the chips contained within each of the ten random squares within the grid were examined for attributes set out in ASTM E770-80.

- Chip height and width were estimated using a brass rod graduated in 2 mm divisions. Estimations were made to within 0.25 mm. The area examined was substantially the same area that would be contacted by the rubber slider of the BPT when the skid resistance tests were carried out.

### 2.2.5 Description of Classification Parameters

In accordance with ASTM E770-80, the surface macro- and microtextures of a pavement are defined in terms of six texture parameters. These texture parameters (Codes A to F) are shown on Figure 2.1.

- **Parameter A:** Height (mm) of the macro-projections.
  The height is defined as the vertical distance above the reference plane (the plane which skims the top of the micro-projections of the pavement matrix, see Figure 2.1) to the top or apex of the macro-projections. For New Zealand roads, a macro-projection is generally a single chip.

  Heights are coded from 0 to 6, increasing as the macro-projection height increases.

- **Parameter B:** Width.
  This is defined as the smallest horizontal dimension (mm) of the projection measured at the reference plane, at the level where the macro-projection meets the top of the matrix.

  Widths are coded from 0 to 6, decreasing as the projection width increases.

- **Parameter C:** Angularity of the macro-projection.
  This is coded as round (1), sub-angular (2), or angular (3).

- **Parameter D:** Density (%) of the macro-projections.
  This is defined as percentages of the total area that the projections occupy.

- **Parameter E:** Harshness of the surfaces of the macro-projections.
  The height and angularity of the micro-projections of the surface of the macro-projections are coded from 0 to 6 as: polished (1), smooth (2), very fine grained (3), fine grained (4), coarse grained subangular (5), and coarse grained angular (6).

- **Parameter F:** Harshness of the matrix surface between the macro-projections.
  The height and angularity of the micro-projections of the matrix surface are coded from 0 to 6 as cavity (0), polished (1), smooth (2), very fine grained (3), fine grained (4), coarse grained subangular (5), and coarse grained angular (6).

In this study, because the matrix consisted of epoxy with a relatively smooth surface, parameter F or the harshness of the matrix surface between the macro-projections (in this case the chip) was coded as smooth (2). In the cases where the epoxy was so thin that the timber of the panel base was exposed, the code was (0) for cavity.

Each of the parameter classifications for each surface in Tables 2.1 and 3.3 is the mean of a number of the individual classification code numbers for the sample squares selected within the grid.

## 2.3 Effect of Operator Training

A training session for operators was undertaken, first to establish a consistent methodology by the first operator in setting up the instrument and levelling the foot between swings, then to ensure that the second operator followed exactly the same method of the first operator. Only the test panels of grades 3 and 5 chip surfaces were used.

After training, the repeatability of single operators and reproducibility of two operators using the same instrument was studied by applying the following steps:

1. Comparison of measurements made on the 10 calibration surfaces used for calibrating the BPT. In this mode the feet of the BPT are placed outside the surface under test so positioning effects are not included. One set of measurements was made by each operator on each of the 10 calibration surfaces.

2. Comparison of measurements made on the test panel surfaces used in the inter-laboratory comparison. In this mode the feet of the BPT are placed on the test surface to include positioning effects. One set of measurements was made by each operator.

3. Comparison of repeat measurements made on two of the test panel surfaces (the grade 3 and grade 5 surfaces) used in the inter-laboratory comparison. This provided a measure of possible improvements in the reproducibility of the instrument with improved operator training. Ten sets of measurements were made by each operator.

4. Comparison of measurements made along a road surface of grade 5 chip, with repeat measurements at the same position. This provided a measure of how representative the test panel surfaces are of the road surface. It also provided a further estimate of reproducibility on the road. Ten sets of measurements were made by each operator at one site on a grade 5 seal road, followed by each operator making one set of measurements at 20 sites on a grade 5 seal road.

Figure 2.1. Pavement surface profile (after ASTM E770-80, Figure 6).

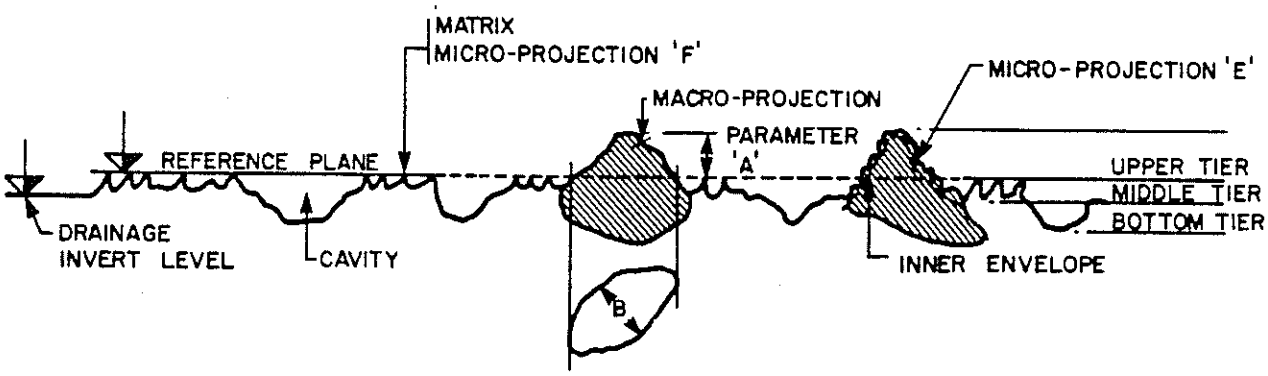


Table 2.1. Surface texture classification (after ASTM E770-80, Table 1).

| Parameter Code | Macrotexture of Projections | | | | Microtexture | |
|---|---|---|---|---|---|---|
| | Approx. Height A (mm) | Approx. Width B (mm) | Angularity C | Density of Distribution as % of Total Area D | Projections Harshness E | Matrix Harshness F |
| 0 | 0 | 16 | ... | enter actual % of total area | ... | cavity in surface of matrix |
| 1 | 0.25 | 8 | round | | polished (no texture visible) | |
| 2 | 0.50 | 4 | subangular | | smooth (texture visible but microprojections too small for visual estimate of height) | |
| 3 | 1 | 2 | angular | | fine-grained (height of microprojections less than 0.25 mm and less than one half of their width) | |
| 4 | 2 | particles less than 2 mm wide are regarded as microtexture | ... | | fine-grained (microprojections approx. 0.25 mm and less than 1.0 mm wide) | |
| 5 | 4 | | ... | | coarse-grained subangular (microprojections approx. 0.5 mm high or more) | |
| 6 | 8 | | ... | | coarse-grained angular (microprojections approx. 0.5 mm high or more) | |

## 2.4 Road Surface Assessment

The nature of the road surface assessment in terms of skid resistance of segments will be determined by the concept of the role that skid resistance plays in the existence of a traffic safety hazard as in the following two situations.

1. If a skid hazard arises because skid resistance within a zone of a road segment is less than some absolute value, then the assessment method should be capable of identifying the zones of low skid resistance.

2. If a skid hazard arises because of differences in skid resistance within a road segment, then the assessment method should be capable of determining the existence of a pattern or rate of variation in skid resistance within a segment, of identifying the different zones and measuring their skid resistance.

The experimental design for this fourth phase of the study could have been chosen to take no account of prior knowledge of likely skid resistance patterns, and to test randomly over the road segment. If the measurement variations were all less than repeatability, that segment could be said, with confidence, to be homogeneous. However, if a range greater than the repeatability was found, the segment could be divided into sub-segments and associated readings could be further analysed to reveal characteristic patterns of variation.

Experience indicates that BPN values on most roads lie between about 50 and 90 BPN and, with repeatabilities of the inter-laboratory comparison being of the order of 25 to 35 BPN, it was unlikely that any statistically significant pattern could be established. This situation would change if operator training could improve the repeatability to reduce it so that it is small compared to the range of BPN values possible. A pattern that is statistically significant could then be established.

A second experimental design was based on the pattern of variation of skid resistance that is known to occur within the segment. Measurements in accordance with that expected pattern, and subsequent analysis of the measurements should then confirm the validity of this basis. The assumptions for this approach are described as follows.

1. A trafficked road segment can be longitudinally divided into: "wheeltracked" areas, which will be associated with lower skid resistance measurements; and "non-wheeltracked" areas, which will usually be associated with higher skid resistance.

   These areas or zones may be further subdivided. The non-wheeltracked areas comprise the shoulder and the zone between the two wheeltracks. The wheeltracked areas are the left wheeltrack and the right wheeltrack.

   For two-way roads the opposite direction lane will have a separate but similar division into zones. The centreline area will be an additional, mainly non-trafficked, zone. These zones can be located by examining the surface and/or observing traffic flows.

2. These longitudinal zones will have a consistent level of skid resistance over 50 m sections. (This length also matches RAMM[2] assessment lengths and would be a suitable size for accident assessment.)

3. The skid resistance of both wheeltracks need not be equal.

4. On curves, tyres have a polishing action such that the skid resistance of the wheeltracks will be less in a radial direction than in the longitudinal direction. There may be an ad hoc relationship with curve radius/traffic speed.

5. The mean skid resistance of each zone can be determined to a 95% level of confidence with less than 10 measurements.

Twelve sites within the Lower Hutt City area were selected for investigation. All sites were at least moderately worn, with wheeltracks evident. Site selection was constrained to locations which had a reasonable traffic volume but were able to be closed off to traffic for the measurement period. The Gracefield Road and Tunnel Grove sites have low volumes of cars but relatively high volumes of heavy traffic. Western Hutt Road, Wainuiomata Hill, Wainuiomata Road, Naenae Road and Fairway Drive have high volumes of light vehicles (about 3000-5000 AADT[3] per lane). Farmers Crescent and Riverside Drive have moderate traffic volumes (500-800 AADT). Traffic was mainly free flowing around the curves.

For each of the 12 sites, the location of the four zones within one lane was determined by inspection. These zones were:

- shoulder area adjacent left hand edge,
- left hand wheeltrack,
- between the wheeltrack, and
- wheeltrack adjacent centreline.

The measurements made were as follows:

- Within each zone: 10 measurement points equally spaced at 5 m intervals were measured.
- At one site only: measurement points were equally spaced at 2.5 m intervals. The number of measurement points was increased to 20.
- On four curve sites: for each of the 10 measurement sites within the two wheeltracks, measurements were made in both a longitudinal direction and a radial direction, away from the centre of curvature.

In all, at least 40 measurements were made at each site. At two sites 60 were made, and at one, 80 measurements were made.

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2 RAMM Road Assessment and Maintenance Management System

3 AADT Average Annual Daily Traffic

**Note:** A choice had to be made between making measurements at random or regularly spaced locations within the zone. Regularly spaced locations were used because the literature about continuous skid resistance instruments such as SCRIM[4] did not indicate that skid resistance variations are of a regular pattern. If patterns had been regular they could cause fixed measurement points to always be located on an unrepresentative area of high or low skid resistance.

# 3. RESULTS

## 3.1 Inter-Laboratory Comparison

The eight participating laboratories tested their BPT on the test panels of sealing chip used as substrates to obtain the results listed in Table 3.1. The results are the averages of the results obtained from each of the five or more individual pendulum swings over each test surface.

Table 3.1. Results (expressed as BPN) obtained for each test panel surface.

| Lab ID No. | Test panel surface ID No.* | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 |
| 1 | 70 | 69 | 96 | 92 | 69 | 85 | 71 | 77 | 88 | 92 | 73 | 69 | 70 | 70 | 61 | 67 |
| 2 | 75 | 77 | 95 | 81 | 81 | 76 | 83 | 87 | 97 | 104 | 81 | 77 | 79 | 79 | 65 | 67 |
| 3 | 66 | 63 | 64 | 75 | 64 | 74 | 85 | 80 | 90 | 84 | 73 | 76 | 77 | 70 | 68 | 64 |
| 4 | 63 | 61 | 65 | 103 | 89 | 73 | 62 | 74 | 67 | 74 | 53 | 63 | 60 | 62 | 57 | 60 |
| 5 | 78 | 75 | 78 | 93 | 91 | 98 | 88 | 86 | 112 | 93 | 84 | 81 | 78 | 67 | - | -** |
| 6 | 78 | 77 | 73 | 85 | 73 | 67 | 89 | 83 | 86 | 82 | 87 | 81 | 75 | 65 | 72 | 73 |
| 7 | 80 | 80 | 96 | 88 | 86 | 78 | 90 | 95 | 85 | 117 | 88 | 89 | 73 | 74 | 89 | 83 |
| 8 | 79 | 80 | 104 | 91 | 86 | 82 | 78 | 94 | 93 | 106 | 78 | 74 | 77 | 76 | 65 | 70 |

* Two measurements on each surface (see Section 2.1 of this report).
** Because of a timing irregularity, Laboratory 5 was excluded from this section of the trial.

## 3.2 Influence of Chip Attributes

Results from the tests of BPT that investigated the relationship of chip size and other surface parameters to BPN, carried out by Works Central Laboratories, are listed in Table 3.2 and Table 3.3.

[4] SCRIM Sideways Force Coefficient Routine Investigation Machine

Table 3.2. BPN of test surfaces, for three different chip sizes and four quarry sources.

| Chip Size | Run No. | BPN Obtained from Chips from Four Quarry Sources | | | |
|---|---|---|---|---|---|
| | | Kiwi Point* Wellington | Winstone's Wellington | Palmer's Dunedin | Winstone's Auckland |
| Grade 3 | 1 | 85 | 74 | 72 | 82 |
| " | 2 | 80 | 74 | 77 | 80 |
| " | 3 | | 60 | 74 | 80 |
| " | 4 | | 61 | 79 | 84 |
| " | 5 | | 61 | 66 | 86 |
| " | 6 | | 70 | 66 | 94 |
| " | 7 | | 75 | 75 | 87 |
| " | 8 | | 66 | 66 | 93 |
| " | 9 | | 71 | 71 | 81 |
| " | 10 | | 70 | 82 | 79 |
| | **Average** | **(83)** | **68** | **73** | **85** |
| Grade 4 | 1 | 90 | 77 | 74 | 87 |
| " | 2 | 84 | 86 | 70 | 87 |
| " | 3 | | 78 | 70 | 77 |
| " | 4 | | 79 | 75 | 88 |
| " | 5 | | 70 | 71 | 86 |
| " | 6 | | 81 | 76 | 86 |
| " | 7 | | 78 | 74 | 80 |
| " | 8 | | 79 | 76 | 91 |
| " | 9 | | 79 | 74 | 80 |
| " | 10 | | 70 | 69 | 85 |
| | **Average** | **(87)** | **78** | **73** | **85** |
| Grade 6 | 1 | 77 | 88 | 80 | 93 |
| " | 2 | 70 | 83 | 70 | 85 |
| " | 3 | | 83 | 69 | 85 |
| " | 4 | | 81 | 70 | 79 |
| " | 5 | | 84 | 73 | 93 |
| " | 6 | | 85 | 73 | 81 |
| " | 7 | | 84 | 72 | 90 |
| " | 8 | | 82 | 75 | 81 |
| " | 9 | | 87 | 75 | 88 |
| " | 10 | | 85 | 71 | 83 |
| | **Average** | **(74)** | **84** | **73** | **86** |

* Values shown are those for Laboratory 3 in inter-laboratory comparison.

**Note:** Apart from the inter-laboratory comparison, measurements in this table and in all subsequent tables in this report are all determined by five or more swings of the BPT until:

- either the first five readings differ by no more than three units, or
- if not, further swings are made until three consecutive readings are constant.

Table 3.3 Pavement texture classification using ASTM E770-80 techniques.

| Quarry Source | Chip Grade | Pavement surface texture parameters* | | | | | | BPN** |
|---|---|---|---|---|---|---|---|---|
| | | A Height | B Width | C Angularity | D Density | E Harshness | F Harshness | |
| Kiwi Point | 2 | >6.0 | 0.7 | 2.3 | 76.5 | 4.2 | 1.2 | 69 |
| | 3 | 5.8 | 0.9 | 2.3 | 80.0 | 4.0 | 2.0 | 83 |
| | 4 | 5.5 | 1.6 | 2.4 | 70.6 | 4.1 | 2.0 | 87 |
| | 5 | 5.0 | 1.4 | 2.6 | 72.0 | 4.4 | 1.5 | 75*** |
| | 6 | 5.1 | 1.8 | 2.4 | 71.5 | 3.4 | 1.6 | 74 |
| Winstone's Wellington | 3 | >6.0 | 0.9 | 2.3 | 63.5 | 3.9 | 1.2 | 68 |
| | 4 | 5.6 | 1.1 | 2.5 | 67.8 | 4.1 | 1.1 | 78 |
| | 6 | 4.5 | 2.1 | 2.6 | 77.0 | 3.8 | 1.8 | 84 |
| Palmer's Dunedin | 3 | >6.0 | 0.8 | 2.4 | 70.6 | 4.1 | 1.0 | 73 |
| | 4 | 5.9 | 1.2 | 2.5 | 70.1 | 4.3 | 1.4 | 73 |
| | 6 | 4.9 | 1.9 | 2.5 | 74.0 | 4.0 | 1.7 | 73 |
| Winstone's Auckland | 3 | >6.0 | 0.8 | 2.8 | 82.6 | 5.2 | 0.8 | 85 |
| | 4 | 5.7 | 1.4 | 2.6 | 71.5 | 5.1 | 1.1 | 85 |
| | 6 | 4.3 | 2.5 | 2.6 | 71.1 | 4.6 | 1.6 | 86 |

* See Table 2.1 and Section 2.2.4 for description of parameters A to F.
** Mean value of measured BPN.
*** Values for test panels of grades 3 and 5 used in the inter-laboratory comparison also included.

## 3.3 Effect of Operator Training

After the training session for operators had been undertaken, the four steps to determine the repeatability of single operators and reproducibility of two operators using the same instrument were carried out. The results are listed in Tables 3.4 - 3.7.

Table 3.4 Measurements obtained by two operators on BPT calibration surfaces*.

| Calibration Surface Number | BPN Obtained by | | Difference in BPN (operator 1–operator 2) |
|---|---|---|---|
| | Operator 1 | Operator 2 | |
| 1 | 9 | 10 | –1 |
| 2 | 69 | 69 | 0 |
| 3 | 66 | 65 | +1 |
| 4 | 76 | 78 | –2 |
| 5 | 84 | 84 | 0 |
| 6 | 87 | 87 | 0 |
| 7 | 61 | 61 | 0 |
| 8 | 58 | 55 | +3 |
| 9 | 83 | 84 | –1 |
| 10 | 88 | 87 | –1 |

**Note:** Instrument is not seated on surface being tested.
* See Section 2.3, Step 1, of this report.

Table 3.5 Measurements obtained by two operators on test panel surfaces used in inter-laboratory comparison*.

| Test panel surface | BPN Obtained by | | Difference in BPN (operator 1–operator 2) |
|---|---|---|---|
| | Operator 1 | Operator 2 | |
| Asphaltic concrete | 72 | 74 | –2 |
| Friction course | 64 | 63 | 1 |
| Grade 2 chipseal | 71 | 70 | 1 |
| Grade 4 chipseal | 71 | 75 | –4 |
| Grade 5 chipseal | 81 | 81 | 0 |
| Grade 6 chipseal | 79 | 74 | 5 |

**Note:** Instrument is seated on surface being tested.
* See Section 2.3, Step 2, of this report.

Table 3.6 Repeat measurements obtained by two operators at the same location on two test panel surfaces and on one road surface*.

| BPN from Test Panel Surface | | | | BPN from Road Surface | |
|---|---|---|---|---|---|
| Grade 3 | | Grade 5 | | Grade 5 chipseal | |
| Operator 1 | Operator 2 | Operator 1 | Operator 2 | Operator 1 | Operator 2 |
| 86 | 80 | 70 | 69 | 86 | 81 |
| 79 | 78 | 74 | 67 | 76 | 76 |
| 84 | 85 | 73 | 72 | 78 | 77 |
| 75 | 78 | 69 | 75 | 77 | 74 |
| 82 | 79 | 76 | 74 | 80 | 75 |
| 84 | 80 | 75 | 70 | 78 | 72 |
| 86 | 75 | 76 | 69 | 84 | 81 |
| 78 | 83 | 74 | 70 | 75 | 77 |
| 85 | 76 | 72 | 74 | 74 | 72 |
| 75 | 75 | 72 | 70 | 78 | 72 |
| **Mean** 81.4 | 78.9 | 73.1 | 71.0 | 78.6 | 75.7 |
| **Std Dev.** 4.10 | 3.11 | 2.26 | 2.49 | 3.61 | 3.22 |

* See Section 2.3, Step 3, of this report.

Table 3.7. Measurements obtained by two operators both measuring the same location for 20 positions at 2.5 m intervals*.

| BPN Obtained by | | Difference in BPN (operator 1–operator 2) |
|---|---|---|
| Operator 1 | Operator 2 | |
| 71 | 70 | 1 |
| 68 | 61 | 7 |
| 75 | 74 | 1 |
| 70 | 70 | 0 |
| 64 | 64 | 0 |
| 79 | 72 | 7 |
| 69 | 70 | –1 |
| 68 | 69 | –1 |
| 69 | 70 | –1 |
| 77 | 78 | –1 |
| 64 | 61 | 3 |
| 64 | 64 | 0 |
| 69 | 70 | –1 |
| 66 | 66 | 0 |
| 70 | 70 | 0 |
| 70 | 69 | 1 |
| 67 | 68 | –1 |
| 68 | 65 | 3 |
| 70 | 68 | 2 |
| 71 | 69 | 2 |
| **Mean** 69.5 | 68.4 | n.a. |
| **Std Dev.** 3.9 | 4.0 | n.a. |

* See Section 2.3, Step 4, of this report.
n.a. not applicable

## 3.4 Road Surface Assessment

The measurements obtained from the road segments studied in phase 4, to assess road surface, are shown in Tables 3.8 to 3.12 of this Section. These tables also contain some of the statistical analysis. This analysis is between the zones of one site and not between zones of different sites.

**Notes for Tables 3.8 to 3.12:**

[1] Zones:

| | | |
|---|---|---|
| Shoulder | - | area adjacent the left hand edge or kerb |
| Outer WT | - | the wheeltrack (WT) closest the left hand edge (with respect to traffic flow) |
| Between WT | - | between wheeltracks |
| Inner WT | - | the wheeltrack adjacent the centreline |

[2] → denotes measurement direction with traffic flow
↑ denotes measurement in radial direction away from the centreline

[3] These tables also contain the statistical analysis of the zones.
The symbol position (*) denotes whether the means are statistically different.

Symbols vertically aligned, i.e. * equates to no statistical difference.
*

Symbols vertically displaced, i.e. * indicates statistical difference.
*

Symbols overlapping, i.e. 1 * indicates that 1 and 3 are statistically different,
2 * * but 2 is not statistically different from 1 or 3.
3 *

Table 3.8 Measurements and analysis of asphaltic concrete sites.

| Site | Zones[1,2] | Measurements at 5 m spacings | | | | | | | | | | Mean | 95% confidence interval | Analysis[3] | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9. Naenae Road Straight | Shoulder | 71 | 69 | 72 | 73 | 75 | 72 | 75 | 73 | 76 | 76 | 73 | 72-74 | | * | The shoulder is clearly distinct. Because the measurement for the other zones are so consistent, the outer WT is also distinct, though the real variation is small. |
| | Outer WT | 59 | 60 | 59 | 59 | 62 | 61 | 60 | 61 | 63 | 63 | 61 | 60-61 | * | | |
| | Between WT | 59 | 61 | 63 | 64 | 62 | 63 | 63 | 64 | 66 | 64 | 63 | 62-64 | | * | |
| | Inner WT | 61 | 62 | 63 | 62 | 64 | 64 | 63 | 64 | 63 | 67 | 63 | 62-64 | | * | |
| 11. Riverside Drive Straight | Shoulder | 72 | 71 | 69 | 66 | 70 | 66 | 70 | 66 | 71 | 74 | 69 | 68-71 | | * | Little difference between zones. |
| | Outer WT | 69 | 70 | 71 | 67 | 66 | 71 | 70 | 69 | 70 | 69 | 69 | 68-71 | * | * | |
| | Between WT | 69 | 66 | 67 | 69 | 66 | 70 | 66 | 70 | 66 | 66 | 67 | 66-69 | * | * | |
| | Inner WT | 64 | 67 | 70 | 66 | 65 | 68 | 63 | 68 | 64 | 65 | 66 | 65-68 | * | | |
| 4. Gracefield Road Curve | Shoulder | 70 | 74 | 77 | 76 | 74 | 76 | 66 | 65 | 68 | 69 | 71 | 70-73 | | * | Outer wheeltrack has shorter radius. Shoulder is distinct. Other zones have little difference. |
| | Outer WT → | 60 | 59 | 66 | 61 | 62 | 61 | 63 | 58 | 63 | 62 | 63 | 62-65 | | * | |
| | Outer WT ↑ | 60 | 59 | 61 | 56 | 61 | 62 | 63 | 59 | 61 | 62 | 61 | 60-63 | * | * | |
| | Between WT | 58 | 59 | 61 | 59 | 60 | 64 | 60 | 60 | 58 | 59 | 60 | 58-61 | * | | |
| | Inner WT → | 64 | 63 | 62 | 65 | 61 | 65 | 65 | 64 | 64 | 60 | 62 | 60-63 | * | * | |
| | Inner WT ↑ | 62 | 62 | 61 | 60 | 60 | 62 | 63 | 62 | 62 | 60 | 60 | 59-62 | * | | |

Table 3.9 Measurements and analysis of grade 3 chipseal sites.

| Site | Zones[1,2] | Measurements at 5 m spacings | | | | | | | | | | Mean | 95% confidence interval | Analysis[3] | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. National Film Unit Straight | Shoulder | 74 | 80 | 70 | 79 | 74 | 75 | 71 | 75 | 75 | 72 | 75 | 72-77 | | * | | Shoulder area clearly distinct. Other three zones indistin-guishable from each other. |
| | Outer WT | 61 | 60 | 59 | 67 | 59 | 55 | 61 | 67 | 64 | 66 | 61 | 58-64 | * | | | |
| | Between WT | 66 | 59 | 64 | 65 | 60 | 64 | 71 | 62 | 60 | 66 | 64 | 61-66 | * | | | |
| | Inner WT | 66 | 65 | 63 | 64 | 65 | 63 | 58 | 74 | 63 | 65 | 65 | 62-67 | * | | | |
| 10. Gracefield Road Straight | Shoulder | 80 | 83 | 66 | 88 | 65 | 77 | 87 | 73 | 85 | 75 | 78 | 74-81 | * | | | Wheeltracks clearly distinct from shoulder. Between wheeltracks not distin-guishable from either shoulder or wheeltracks. |
| | Outer WT | 67 | 71 | 71 | 66 | 65 | 61 | 66 | 75 | 68 | 62 | 67 | 64-71 | | * | | |
| | Between WT | 80 | 68 | 65 | 75 | 78 | 64 | 72 | 69 | 70 | 75 | 72 | 68-75 | * | * | | |
| | Inner WT | 65 | 66 | 74 | 75 | 67 | 68 | 70 | 66 | 70 | 70 | 69 | 66-73 | | * | | |
| 5. Gracefield Road Curve | Shoulder | 65 | 72 | 75 | 74 | 76 | 70 | 73 | 78 | 73 | 74 | 73 | 70-76 | | | * | Shoulder area clearly distinct. Radial direction clearly distinct in one wheeltrack from longitudinal direction. Different but not at 95% confidence for other wheeltrack. Inner wheeltrack has shorter radius. |
| | Outer WT → | 53 | 60 | 55 | 63 | 65 | 57 | 58 | 65 | 65 | 56 | 62 | 57-63 | | * | * | |
| | Outer WT ↑ | 45 | 49 | 52 | 55 | 58 | 56 | 54 | 52 | 57 | 53 | 54 | 51-57 | * | | | |
| | Between WT | 66 | 55 | 54 | 62 | 59 | 60 | 58 | 58 | 61 | 63 | 60 | 57-63 | | * | * | |
| | Inner WT → | 75 | 70 | 63 | 55 | 59 | 59 | 61 | 62 | 64 | 65 | 63 | 60-66 | | | * | |
| | Inner WT ↑ | 56 | 56 | 55 | 55 | 55 | 53 | 58 | 55 | 63 | 64 | 57 | 54-60 | | * | * | |

Table 3.10 Measurements and analysis of grade 5 chipseal sites.

| Site | Zones[1,2] | Measurements at 5 m spacings | | | | | | | | | | Mean | 95% confidence interval | Analysis[3] | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Tunnel Grove Straight | Shoulder | 83 | 74 | 76 | 83 | 81 | 76 | 76 | 75 | 75 | 79 | 78 | 75-80 | | | * | |
| | Outer WT | 85 | 66 | 70 | 68 | 70 | 74 | 66 | 65 | 66 | 70 | 71 | 68-73 | | * | | |
| | Between WT | 65 | 61 | 69 | 71 | 72 | 66 | 69 | 70 | 60 | 65 | 67 | 64-69 | * | * | | |
| | Inner WT | 65 | 64 | 60 | 64 | 62 | 67 | 64 | 69 | 62 | 65 | 64 | 62-67 | * | | | |
| 7. Farmers Crescent Straight | Shoulder | For detailed measurements, see Table 3.12 | | | | | | | | | | 78 | 76-80 | | * | | |
| | Outer WT | | | | | | | | | | | 71 | 69-72 | * | | | |
| | Between WT | | | | | | | | | | | 69 | 66-71 | * | | | |
| | Inner WT | | | | | | | | | | | 69 | 66-70 | * | | | |
| 6. Farmers Crescent Curve | Shoulder | 73 | 67 | 67 | 72 | 69 | 66 | 80 | 72 | 65 | 65 | 70 | 67-72 | | | * | Inner wheeltrack has shorter radius. |
| | Outer WT → | 59 | 58 | 58 | 64 | 64 | 69 | 64 | 60 | 69 | 60 | 63 | 60-65 | | * | | |
| | Outer WT ↑ | 60 | 55 | 59 | 58 | 64 | 66 | 65 | 57 | 64 | 60 | 61 | 58-63 | * | * | | |
| | Between WT | 62 | 60 | 64 | 60 | 62 | 58 | 56 | 57 | 62 | 65 | 61 | 58-63 | * | * | | |
| | Inner WT → | 59 | 58 | 55 | 60 | 56 | 61 | 55 | 59 | 56 | 60 | 58 | 56-60 | * | * | | |
| | Inner WT ↑ | 57 | 59 | 58 | 55 | 51 | 54 | 54 | 59 | 55 | 60 | 56 | 54-56 | * | | | |

Table 3.11 Measurements and analysis of friction course sites.

| Site | Zones[1,2] | Measurements at 5 m spacings | | | | | | | | | | Mean | 95% confidence interval | Analysis[3] | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3. Wainuiomata Road Straight | Shoulder | 60 | 60 | 63 | 58 | 59 | 60 | 69 | 60 | 64 | 60 | 61 | 60-63 | | * | | The shoulder is distinct. Other zones indistinguishable. |
| | Outer WT | 54 | 51 | 55 | 54 | 55 | 54 | 50 | 56 | 55 | 56 | 54 | 52-56 | * | | | |
| | Between WT | 54 | 55 | 56 | 52 | 59 | 57 | 54 | 53 | 62 | 56 | 56 | 54-57 | * | | | |
| | Inner WT | 58 | 54 | 57 | 50 | 54 | 54 | 55 | 59 | 59 | 56 | 56 | 54-57 | * | | | |
| 12. Western Hutt Motorway Straight | Shoulder | 71 | 67 | 74 | 70 | 70 | 70 | 69 | 65 | 69 | 61 | 69 | 67-70 | | * | | Only shoulder is distinct. |
| | Outer WT | 57 | 61 | 61 | 62 | 63 | 59 | 69 | 67 | 70 | 68 | 64 | 62-65 | * | | | |
| | Between WT | 69 | 65 | 66 | 65 | 64 | 64 | 61 | 64 | 64 | 62 | 64 | 63-66 | * | | | |
| | Inner WT | 64 | 67 | 62 | 61 | 59 | 63 | 62 | 62 | 60 | 64 | 62 | 61-64 | * | | | |
| 8. Wainuiomata Hill Curve | Shoulder | 75 | 75 | 64 | 75 | 70 | 65 | 73 | 72 | 67 | 70 | 71 | 68-73 | | | * | Shoulder distinct. Between wheeltracks nearly significantly different. Inner wheeltrack is shorter radius. |
| | Outer WT → | 52 | 55 | 59 | 56 | 64 | 55 | 57 | 62 | 56 | 56 | 57 | 55-59 | * | * | | |
| | Outer WT ↑ | 59 | 57 | 63 | 52 | 57 | 55 | 55 | 56 | 59 | 58 | 57 | 55-59 | * | * | | |
| | Between WT | 64 | 61 | 62 | 55 | 60 | 55 | 61 | 63 | 63 | 61 | 61 | 58-63 | | * | | |
| | Inner WT → | 55 | 59 | 59 | 54 | 56 | 57 | 60 | 56 | 55 | 56 | 57 | 54-59 | * | * | | |
| | Inner WT ↑ | 53 | 54 | 56 | 51 | 62 | 53 | 54 | 49 | 51 | 52 | 54 | 51-56 | * | | | |

Table 3.12 Measurements for site 7, a grade 5 chipseal (see Table 3.10 for analysis).

| Measurement Position | | BPN Obtained from Zones | | | | | |
|---|---|---|---|---|---|---|---|
| | | Shoulder | Outer WT | | Between WT | Inner WT | |
| 5 m | 2.5 m | | Operator 1 | Operator 2 | | Operator 1 | Operator 2 |
| 1 | 1.0 | 79 | 71 | 70 | 70 | 64 | 61 |
| | 1.5 | | 72 | | | 71 | |
| 2 | 2.0 | 74 | 68 | 61 | 65 | 64 | 64 |
| | 2.5 | | 64 | | | 71 | |
| 3 | 3.0 | 78 | 75 | 74 | 65 | 69 | 70 |
| | 3.5 | | 67 | | | 69 | |
| 4 | 4.0 | 83 | 70 | 70 | 70 | 66 | 66 |
| | 4.5 | | 65 | | | 66 | |
| 5 | 5.0 | 80 | 64 | 64 | 66 | 70 | 70 |
| | 5.5 | | 74 | | | 68 | |
| 6 | 6.0 | 80 | 79 | 72* | 72 | 70 | 69 |
| | 6.5 | | 71 | | | 64 | |
| 7 | 7.0 | 84 | 69 | 70 | 71 | 67 | 68 |
| | 7.5 | | 74 | | | 71 | |
| 8 | 8.0 | 65 | 68 | 69 | 65 | 68 | 65 |
| | 8.5 | | 75 | | | 66 | |
| 9 | 9.0 | 79 | 69 | 70 | 70 | 70 | 68 |
| | 9.5 | | 69 | | | 72 | |
| 10 | 10.0 | 78 | 77 | 78 | 71 | 71 | 69 |

* Poor site measurement, interference from a single non-representative chip.
Site 7 is Farmers Crescent straight.

# 4. ANALYSES OF DATA

## 4.1 Inter-Laboratory Comparison

The data obtained from the inter-laboratory comparison were analysed according to the procedures of ASTM Method E691-92 (ASTM 1992) using a PC software package supplied by ASTM for this purpose. Table 4.1 summarises the results and the salient findings of the analysis are then described.

Table 4.1 Summary of results of analysis of inter-laboratory comparison.

| Test Panel Surface | | Average of BPN | Repeatability (in BPN) | Reproducibility (in BPN) |
|---|---|---|---|---|
| Description | Test Panel No. | | | |
| Mix 10 asphaltic concrete | 1 | 73.2 | 3.8 | 19.6 |
| Grade 2 chipseal hand-placed | 2 | 86.2 | 34.1 | 34.8 |
| Grade 2 chipseal | 3 | 79.5 | 19.8 | 26.7 |
| Grade 3 chipseal | 4 | 82.6 | 16.3 | 24.9 |
| Grade 4 chipseal | 5 | 91.9 | 29.0 | 37.4 |
| Grade 5 chipseal | 6 | 76.7 | 10.0 | 27.3 |
| Grade 6 chipseal | 7 | 72.0 | 11.6 | 17.2 |
| Friction course | 8 | 68.6 | 8.4 | 25.1 |

- Reproducibility and repeatability values are plotted against BPN in Figures 4.1(a) and 4.1(b). Least squares straight line fits are also shown, with dotted curves indicating the corresponding range in which 95% of observed repeatabilities and reproducibilities are expected to lie.

  Over the range of BPN observed, the higher BPN generally tend to correspond to higher variability. The best straight linear relationships to the data in Table 4.1 are:

  Repeatability = (1.164 x BPN) – 75.1
  Reproducibility = (0.734 x BPN) – 31.2

  These linear relationships are not strong, with values of repeatability and reproducibility predicted to an accuracy of around ±14 (at the 95% confidence level). It is therefore not appropriate to assign repeatability and reproducibility for measured BPN as other significant factors not related to skid resistance level may affect results.

  However, on the basis of the data obtained so far, approximate upper limits at the 95% confidence level for repeatability and reproducibility can be given. Maximum repeatability ranges from about 20 units at a BPN of 68, to 48 at a BPN of 92 (Figure 4.1(a)). Reproducibility ranges from 30 to 48 over the same intervals of BPN values (Figure 4.1(b)).

**Key:** — best linear fit to data. - - - - corresponding limits within which 95% of observed repeatability and reproducibility values are expected to lie.

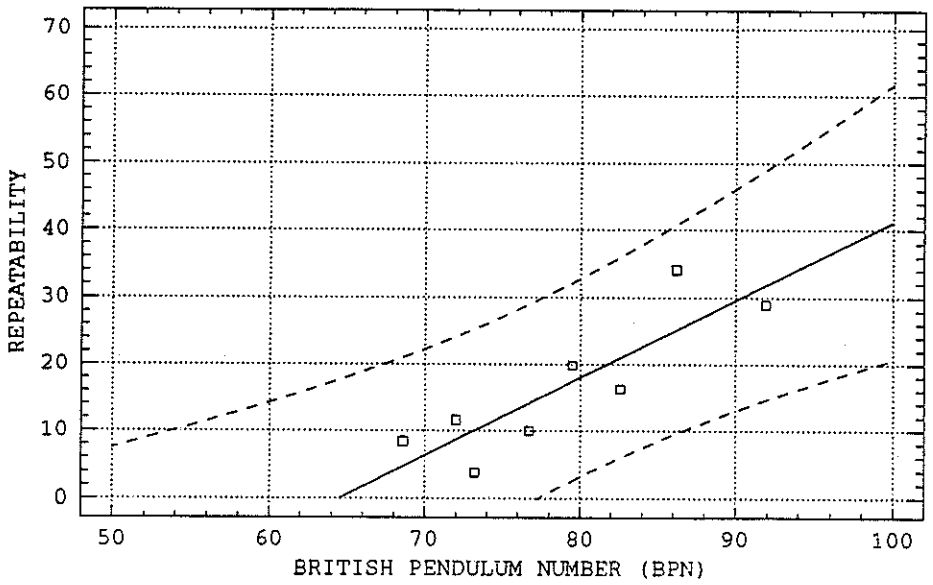



Figure 4.1(a) Repeatability v BPN.

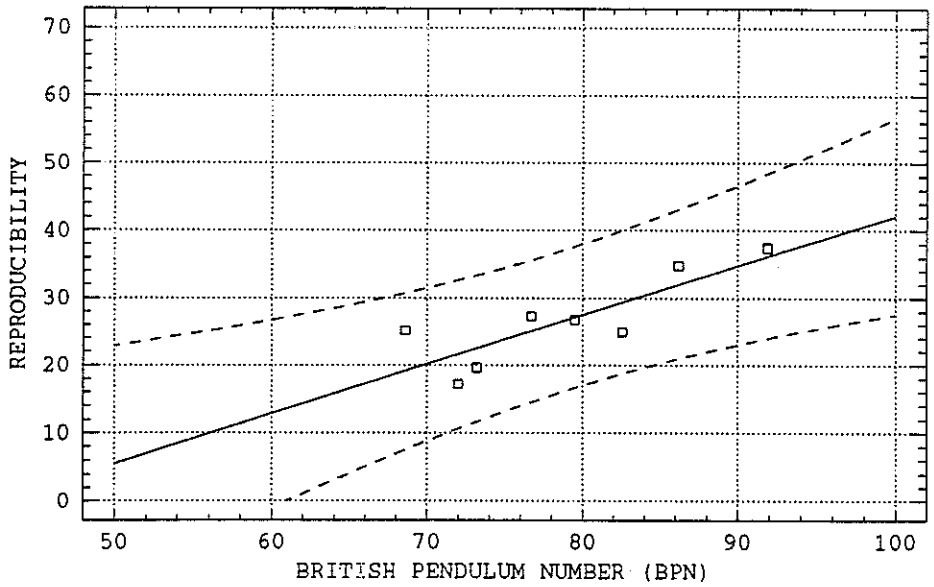



Figure 4.1(b) Reproducibility v BPN.

These maximum reproducibility values indicate that a BPN of approximately 70 can be known to an accuracy of only ±22 units and a BPN of approximately 90 to an accuracy of ± 46 units (at the 95% confidence level).

- Outside the range of skid resistance levels studied, no values for repeatability can be safely assigned. The observed downward trend of variabilities with reducing BPN must cease at some point, and as repeatability must always be less than reproducibility, repeatability and reproducibility values cannot go on converging at the same rate with decreasing BPN.

- Examination of the data indicated sources of systematic error in the method. Laboratories 1, 3 and 4 produced values less than the average for most surfaces tested, and Laboratories 5, 7 and 8 produced values greater than the average values.

  Data from all laboratories, however, were acceptable according to the statistical criteria specified in the standard ASTM E691-87 (ASTM 1987).

- The determined values of repeatability and reproducibility allow the gain in accuracy of repeat testing to be assessed. A mean value over n results can be assumed at the 95% confidence level to be within a range of the true value given by:

$$\pm \frac{1}{\sqrt{2}} \sqrt{R^2 - \left(1 - \frac{1}{n}\right) r^2}$$

  where R and r are reproducibility and repeatability respectively.

  Evaluation of the range n = 1, 2 and 3 indicated that taking two or three tests gives only minor improvement over a single result, and repeat testing will not generally improve reproducibility.

- Asphaltic materials (see test panel 1, mix 10 asphaltic concrete) and the friction course (see test panel 8, friction course) have the lowest BPN values. It is expected that in practice the BPN value would rise (increased friction) as the upper surface of the friction course and asphalt was trafficked and the bitumen was removed from the top of the stones.

  For the inter-laboratory comparison, the trend is for BPN to rise to a maximum at grade 4, then fall off for grades 5 and 6. This apparent trend instigated the expansion of the study to include a study of the influence of the chip attributes.

- The grade 2 chipseal that was hand-prepared to obtain maximum chip interlock (test panel 2) has a higher BPN value than the standard grade 2 chipseal (test panel 3), possibly because the more ordered surface gives a greater slider contact area. This suggests that stone chip shape and degree of trafficking (which re-orients the stones) can influence measured BPN values. It is also in line with in-field results where the BPN values of trafficked asphalt can be high.

## 4.2 Influence of Chip Attributes

### 4.2.1 Chip Size and Source

The data of Table 3.2 (BPN versus chip size and source, Section 3.2 of this report) were analysed both in terms of the mean values and the repeatabilities associated with each value. These averages and repeatabilities are shown in graphical form in Figures 4.2 and 4.3. In Figure 4.2 the mean BPN is examined by chip size (grade) and by source (quarry).

The pattern of BPN rising with decreasing chip size to grade 4, then decreasing for grades 5 and 6 chip, for the Kiwi Point Quarry is not repeated with chip from the other three quarries. For the chip from Winstone's Auckland and Palmer's Dunedin, both basalts, the BPN is relatively constant as chip size increases, while the BPN for the chip from Winstone's Wellington (greywacke) increases as chip size decreases.

Thus to relate the BPN of a chipseal surface according to the chip size is not possible. This supports in part the existing theory that the BPT measures mainly microtexture. One guestimate is that about 80% of the BPN value is derived from microtexture and only 20% from macrotexture. Microtexture could be expected to be more a feature that is specific to the rock crushing process within each quarry, so a relatively constant value of BPN for each chip type could be expected. The results from two quarries supports this expectation, but it is not sustained for the other two quarries. Note, however, that these BPN are of unworn chip. If chip was worn and polished, a more uniform trend may develop.

Figure 4.3 shows the repeatability of the BPNs by size and by source (quarry). Again, while some trends can be discerned, no clear pattern of repeatability can be associated with a chip size, quarry or BPN.

The trends that can be discerned in Figures 4.2 and 4.3 are:

- Repeatabilities, excluding outliers, are typically of the order of about 7 to 18 BPN, for most surfaces. This is in accordance with the general findings of the inter-laboratory comparison.

- Repeatability is generally lower for the smaller chip sizes from a particular quarry. Again, this is in accordance with the earlier study.

The trend for increasing repeatability with increasing BPN found in the inter-laboratory comparison has held for only one quarry (Winstone's Auckland) of these additional chip sources. Palmer's (Dunedin) shows increasing repeatability with BPN relatively constant, and Winstone's (Wellington) shows an increasing repeatability with decreasing BPN.

Figure 4.2 Mean BPN versus chip size (grade) and by source.

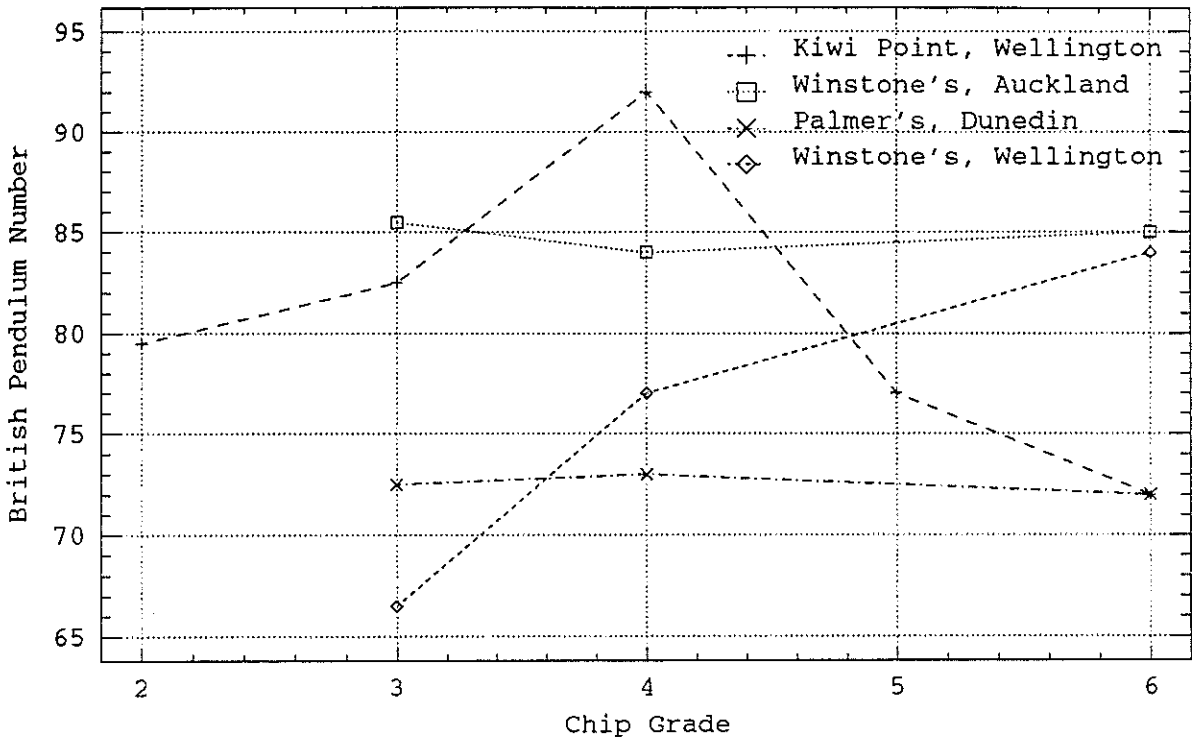
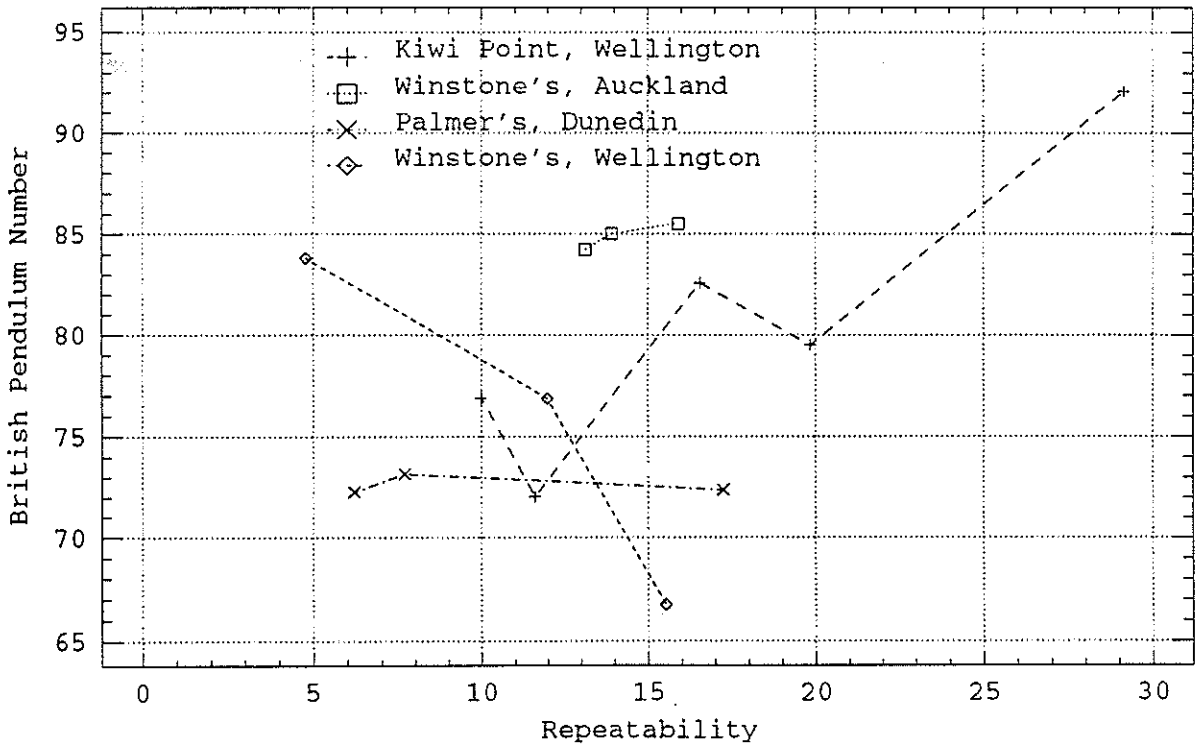



Figure 4.3 Repeatability of BPN by source (from four quarries).



### 4.2.2 Surface Texture Parameters

A series of statistical regressions of the texture parameters that were assessed by visual inspection, adopted from ASTM E770-80 (ASTM 1980) for classifying pavement surface textures, was carried out. In summary, these parameters are:

- Parameter A height
- Parameter B width
- Parameter C angularity
- Parameter D density
- Parameter E harshness of surface of macro-projections, measured by height and angularity of micro-projections
- Parameter F harshness of matrix surface, measured by height and angularity of micro-projections

In the analysis, singular relationships were first examined. Linear, reciprocal square, square root, logarithmic and exponential relationships were tested. For these the $R^2$ value (for the proportion of variance) was low, being of the order of 5-25%.

Next, a series of logical combinations of the pavement surface texture parameters were examined in turn. These and the $R^2$ values are shown in Table 4.2.

Table 4.2 Possible combinations of pavement surface texture parameters to predict BPN.

| Parameter combination (see Table 3.3) | $R^2$ (%) | $R^2$(adj) (%) | Equation |
|---|---|---|---|
| A x B | 6.1 | 0 | |
| 1/C x $e^E$ | 20.2 | 13.6 | |
| A x B x $e^F$ | 9.9 | 2.4 | |
| 1/C x $e^E$ x $e^F$ | 47.9 | 43.6 | BPN = 66.3 x 0.106 (1/C x $e^{E+F}$) (1) |
| 1/A x 1/C | 1.6 | 0 | |
| $e^B$ x $e^E$ x $e^F$ | 21.5 | 14.9 | |
| 1/A x $e^B$ x $e^E$ x $e^F$ | 21.7 | 15.2 | |
| (A x B) + (1/C x $e^E$) | 29.6 | 16.9 | |
| (A x B x $e^F$) + (1/C x $e^E$ x $e^F$) | 48.8 | 39.5 | |
| (A x B) + (1/C x $e^E$) + $e^F$ | 53.8 | 40.0 | BPN = 54.2 + 0.167 (A x B) + 0.369 (1/C x $e^E$) + 2.90 $e^F$ (2) |
| (A x B) + (1/C x $e^E$ x $e^F$) | 48.1 | 38.7 | |
| (1/A x 1/C) + ($e^B$ x $e^E$ x $e^F$) | 27.7 | 14.5 | BPN = 65.5 + 0.140 (A x B) + 0.105 (1/C x $e^{E+F}$) (3) |
| 1/A + $e^B$ + 1/C + $e^E$ + $e^F$ | 55.2 | 27.2 | |
| C1 C2 C3 C4 C5 C6 | 55.9 | 18.1 | |

$R^2$ = Proportion of variance.

$R^2$(adj) = Adjusted value for proportion of variance.

The parameter combinations shown by equations (1), (2) and (3) in Table 4.2 produce the three best fits to the data. For these equations, $R^2$ (adj) also is shown in Table 4.2 and is in the region of 40% for all three of them. This is not high, but can be regarded as indicative of a significant trend.

Each of these three equations contains a large constant term of the order of 55-65 BPN. This is a reflection of the unworn nature of the chips used on the test surfaces, indicating that most of the BPT measurements were comparatively high. This term would be lower if the data had included measurements from worn surfaces.

For each equation, the term relating to macrotexture (i.e. parameters A x B) is either non-existent or small, and the term relating to microtexture (i.e. parameters E and F) is relatively large.

These equations were then used to predict the BPN from the measured parameters that had been used in the analysis and, in Table 4.3 that follows, the result predicted by using these equations with the parameters of Table 3.3 are compared with the mean measured BPN result of Table 3.3.

Table 4.3 Comparison of measured v predicted BPN (using the equations in Table 4.2).

| **Test Surface** | | **British Pendulum Number (BPN)** | | | |
|---|---|---|---|---|---|
| | | **Measured** | **Predicted by**** | | |
| **Quarry** | **Chip Size** | | **Equation (1)** | **Equation (2)** | **Equation (3)** |
| Kiwi Point* | 3 | 83 | 85 | 85 | 85 |
| Winstone's (Wgtn) | 3 | 68 | 74 | 73 | 74 |
| Palmer's (Dn) | 3 | 73 | 74 | 72 | 73 |
| Winstone's (Auck) | 3 | 85 | 80 | 83 | 80 |
| Kiwi Point | 4 | 92 | 82 | 83 | 83 |
| Winstone's (Wgtn) | 4 | 78 | 74 | 73 | 74 |
| Palmer's (Dn) | 4 | 73 | 79 | 78 | 79 |
| Winstone's (Auck) | 4 | 85 | 86 | 86 | 86 |
| Kiwi Point | 6 | 72 | 73 | 75 | 73 |
| Winstone's (Wgtn) | 6 | 84 | 77 | 80 | 78 |
| Palmer's (Dn) | 6 | 73 | 79 | 80 | 79 |
| Winstone's (Auck) | 6 | 86 | 86 | 85 | 87 |
| Kiwi Point | 2 | 79 | 76 | 75 | 76 |
| Kiwi Point | 5 | 77 | 81 | 80 | 81 |

* Values for Kiwi Point chip taken from laboratory 3, in Table 3.2 of this report.
** See equations in Table 4.2.

The differences in measured versus predicted BPN for each equation are shown in Table 4.4, where a prediction greater than the measured number is a positive difference.

Table 4.4 Difference in measured v predicted BPN (using the equations in Table 4.2).

| Chip Size* | Measured BPN | Difference of Measured v Predicted BPN** | | |
|---|---|---|---|---|
| | | Equation (1) | Equation (2) | Equation (3) |
| 3 | 83 | 2 | 2 | 2 |
| 3 | 68 | 6 | 5 | +6 |
| 3 | 73 | 1 | −1 | 0 |
| 3 | 85 | −5 | −2 | −5 |
| 4 | 87 | −5 | −4 | −4 |
| 4 | 78 | −4 | −5 | −4 |
| 4 | 73 | 6 | +5 | 6 |
| 4 | 85 | 1 | 1 | 1 |
| 6 | 74 | −1 | +1 | −1 |
| 6 | 84 | −7 | −4 | −6 |
| 6 | 73 | 6 | 7 | +6 |
| 6 | 86 | 0 | −1 | 1 |
| 2 | 69 | +7 | +6 | +7 |
| 5 | 75 | 6 | 5 | 6 |

* Note that the order of test panel surfaces is the same as that shown in Table 4.3.
** See equations in Table 4.2.

Of these three equations, equation (2) is preferred as it appears to give the best fit to the measured numbers:

$$BPN = 54.2 + 0.167\,(A \times B) + 0.369\,(1/C \times e^{E}) + 2.90\,e^{F} \qquad \text{Equation (2)}$$

The relevance of parameter F in this study is uncertain and, in this regard, equation (2) is also preferred in that it contains the parameter F term as an additive rather than multiplicative component of the equation (as it is in equations (1) and (3)), which minimises its effect.

This part of the analysis helps to demonstrate that there is a closer relationship between skid resistance, expressed as BPN, and the specific properties of the chip (such as shape, angularity and microtexture), than broader considerations such as quarry source or aggregate grade. However, the extent of the relationship is not strong and it is apparent that the selection of chip for an intended initial skid resistance is a complex task.

## 4.3 Effect of Operator Training

Operator training appears to have been successful in that:

- The results obtained by the individual operators are statistically indistinguishable;
- If the two operators are treated as a combined operator, then repeatability has been reduced from that of the inter-laboratory comparison;
- If the two operators were considered as "separate" laboratories, each with a perfectly calibrated instrument, the reproducibility is markedly reduced from the inter-laboratory comparison.

Tables 3.4 and 3.5 in this report show that, for a single test on a common surface, the result for the individual operators most often agreed within one BPN.

Table 3.6 shows that, for multiple testing on either the test panel surfaces or the roads, a one-way analysis for each test surface gives results for each operator that are statistically indistinguishable.

An analysis of the paired data of Table 3.7 shows also that the operators are indistinguishable. However, though not statistically significant, from visual inspection there appears to be a weak trend in Tables 3.6 and 3.7 for operator 2 to produce a marginally lower result than operator 1.

On the grade 3 test panel surface the inter-laboratory comparison produced a repeatability of 16.3 BPN. For the two operators the repeatability is improved to 10.3 BPN. On the grade 5 test panel the inter-laboratory comparison produced a repeatability of 10.0 BPN. For the two operators, the repeatability is improved to 6.8 BPN (derived using information from Table 3.6).

If the operators were considered as "separate" laboratories with instruments that were both perfectly matched, then the reproducibility is very significantly reduced, from the approximately 25 BPN of the inter-laboratory comparison, to about 10 BPN.

## 4.4 Road Surface Assessment

The first part of the analysis, shown in Tables 3.8 to 3.11, examined the means of the measurements from each zone and tested for statistical significance. This has shown:

- Four distinct longitudinal zones within the 50 m segment. Along these zones measured BPN fluctuates, though it does so randomly and there is no pattern of a trend for BPN to rise or fall progressively along the zone.

- Of the zones, the wheeltracks show the lowest BPN, between wheeltracks the BPN is only slightly greater, but the shoulder areas always have a clearly greater BPN value (all sites selected were well trafficked).

- The range of BPN values in the wheeltracks, although about a lower mean, does not appear to be any greater than the range of values about the higher mean of the shoulder areas.

- On most straight road segments the right hand wheeltrack has the lowest BPN. This may arise from additional trafficking of vehicles moving in the opposite direction.

- On all four curves of the road surface study, BPN in the wheeltracks are lower in the radial direction than in the longitudinal direction. Of the eight wheeltracks, the difference is statistically significant in one case. In three cases it is a strong trend, not statistically significant to the 95% confidence level, and in three cases it is a weak trend. In one case there is no difference.

  In three of the four curves, the inner wheeltrack has the lower BPN (both longitudinally and radially). However, the inner wheeltrack has the shortest radius (i.e. a right hand curve) for only two of these three curves.

A further analysis of Tables 3.8 to 3.11 (in Section 3 of this report) shows that the range of values within each zone (maximum to minimum) appears to be related to the size of the surface texture. The average range for the zones in each site is shown in Table 4.5, in which the average range for the grade 3 surface is about double that for the asphaltic surface. Figure 4.4 shows the measurements for each zone for one each of the four surface types measured.

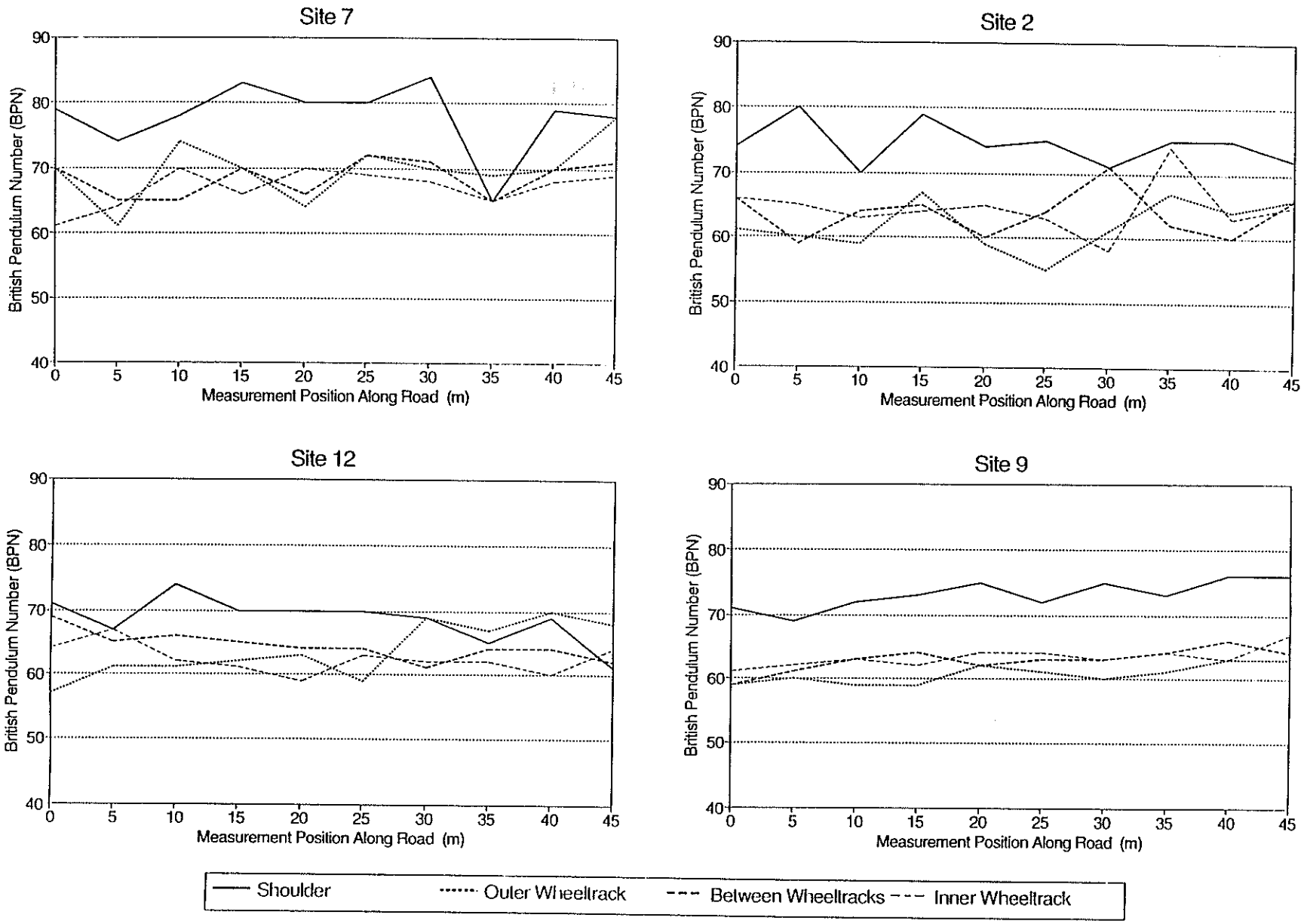
Table 4.5 Range of BPN values obtained with measurements within a 50m road segment (in order of increasing BPN).

| Site | Surface Type | Av. range of BPN * | Av. range of BPN** |
|---|---|---|---|
| 9 | Asphaltic concrete | 5.5 | |
| 11 | " | 5.5 | |
| 4 | " | 6.6 | |
| (All) | | | 6 |
| 3 | Friction course | 7.8 | |
| 12 | " | 9.8 | |
| 8 | " | 10.0 | |
| (All) | | | 9.3 |
| 1 | Grade 5 | 12.2 | |
| 7 | " | 12.2 | |
| 6 | " | 11.6 | |
| (All) | | | 11.4 |
| 2 | Grade 3 | 11.8 | |
| 10 | " | 15.0 | |
| 5 | " | 13.3 | |
| (All) | | | 13.4 |

* Average range of BPN along each zone for all zones at that site.

** Average range of BPN for all sites of surface type.

Figure 4.4 BPN related to position along road at sites 7 (grade 5), and 2 (grade 3), and at sites 12 (friction course), and 9 (asphaltic concrete).



A further analysis showed that when a smaller number of samples was chosen from each zone, the means were statistically equal for a sub-sample of about five sites. Table 4.6 shows 10 selections of five values taken from the outer wheeltrack recorded in Table 3.12. This selection has been constrained so that each selection is made at intervals of 7.5 to 12.5 m along the line. Clearly, little extra precision has been achieved by using the additional measurement positions.

Table 4.6 Mean and standard deviation of 10 selected sub-sets of positions along outer wheeltrack (from Table 3.12 in this report).

| Sample | No. of positions | Mean (BPN) | Std dev. (BPN) | Difference mean from sample |
|---|---|---|---|---|
| Main sample | 20 | 70.9 | 4.28 | n.a. |
| Sub-sample | | | | |
| 1 | 5 | 69.6 | 3.55 | 1.3 |
| 2 | 5 | 72.4 | 4.67 | –1.5 |
| 3 | 5 | 71.0 | 3.92 | –0.1 |
| 4 | 5 | 70.4 | 5.20 | 0.6 |
| 5 | 5 | 69.0 | 3.40 | 1.9 |
| 6 | 5 | 71.8 | 2.48 | –0.9 |
| 7 | 5 | 72.8 | 5.30 | –1.9 |
| 8 | 5 | 70.6 | 6.20 | 0.2 |
| 9 | 5 | 67.8 | 3.20 | 3.1 |
| 10 | 5 | 73.0 | 4.70 | –2.1 |

An analysis of other sites show too that there is a small improvement in precision by increasing the sub-sample from three positions to five, but thereafter the improvement with additional samples is not significant.

# 5. DISCUSSION

## 5.1 BPT Repeatabilities and Reproducibilities

### 5.1.1 Concerns

The first phase of this study provides strong support that the concerns, outlined in Section 1.2 of this report, of wide margins of repeatability and reproducibility when testing chipseal surfaces are justified. The study indicates that the reasons for these wide margins do not lie with kick back and bucking of the instrument, but rather with difficulties in consistently replacing the instrument in exactly its previous position on the road surface, and the difficulty of accurate adjustment of the slider contact distance on larger aggregates. The difficulty with location is also considered not to be one of seating the BPT firmly.

The findings of phase 1 of this study have to be considered with the findings of phases 3 and 4, and also with findings of related work on pedestrian surfaces laid with ceramic tiles (Dravitzki et al. 1992). Phases 3 and 4 show that, with very careful attention to detail, closer repeatabilities and reproducibilities can be obtained. However, the repeatabilities are still significantly large, much larger, for example, than those which are recorded when measuring slip resistance of comparatively smooth ceramic tiles.

The road surface assessments of phase 4 indicate much more consistent measurements than those obtained for the test panel surfaces of phase 1. However, further inspection shows a reasonable consistency of phase 4 with the inter-laboratory comparison. Table 3.6 (in Section 3.3 of this report) shows that both operators obtained an identical pattern of measurements for repeat measurements on both the test panel and road surface, which demonstrates that the test panels were representative. Table 4.5 (in Section 4.4) shows the average range between maximum and minimum values for each of the sites, and that there is a similarity to the repeatabilities found during the inter-laboratory comparison. Also the range for some road segment zones (recorded in Tables 3.8 - 3.11) is about 70% higher than the average values. Because the variations in BPN along any zone (see Figure 4.4) are more or less random and show no steady trend to increase or decrease, the variations probably are actual variations of repeatability of measurements on a surface of reasonably consistent BPN.

Work with the BPT to assess the safety of tiled pedestrian areas obtained more consistent measurements (Dravitzki et al. 1992). Four different operators measuring the BPN of ceramic tiles can quite readily obtain repeat readings within 1 or 2 BPN. This result can be achieved whether the instrument is seated on the test surface (if it has large enough area) or off it, as the surface is comparatively flat.

Table 3.4 (in Section 3.3 of this report) shows that, even when testing rougher surfaces, two operators could produce a close match, but in these tests the calibration test surfaces were small in area and the BPT was not seated on the test surface. For

the inter-laboratory comparison of the asphalt and friction course, the locating feet of the BPT actually sat on the smooth wooden surround of the test piece and a reasonably consistent result was again obtained. However, when the instrument is placed on more irregular chipseal surfaces, the repeatabilities increase.

### 5.1.2 Difficulty in Seating BPT Firmly on Road Surface

Surfaces of larger chip sizes may give considerable variation in skid resistance, even when two areas of measurement partially overlap. The large repeatabilities found in this study may arise from real variations in the actual skid resistance of adjacent areas on the chipseal surface, and that the BPT has measured these variations accurately. These results would indicate that it is a very sensitive instrument, rather than an instrument that is unable to produce a consistent result on this type of surface. Evidence for its sensitivity is that, once seated securely, a consistent measurement can usually be achieved for that position relatively quickly. However, once the BPT is shifted, the instrument is difficult to relocate and reset exactly in the identical contact position, thereby leading to the variations recorded. Because the BPT samples a small area (75 x 125 mm) relative to the size of the aggregates, it may be very sensitive to positioning effects.

On the smaller chip sizes, such as grades 5 and 6 chipseals, consistent placement and accurate slider path adjustment may be achievable, thereby consistently giving smaller repeatabilities. On the larger chipseals, grades 2 to 4, the pattern is less consistent. Repeatabilities are larger, but do not relate well to chip size. For example, the hand-placed grade 2 test surface has a repeatability of 34 BPN, whereas the randomly placed grade 2 has one of 20 BPN, yet the reverse would appear to have been more likely. The grade 4 chipseal has a similarly large repeatability of 29 BPN, which is considerably higher than that for the grade 3 chip, which has a repeatability of 16 BPN. There are therefore effects other than those of positioning of the instrument.

### 5.1.3 Slider Adjustment and Chip Size

The accurate adjustment of the slider path can be particularly difficult on chipseals. Setting the slider distance can be affected by whether a hard or soft contact is made with the test surface. The irregular nature of the surface may mean that a single chip is initiating the first or last contact so that in effect the contact area is reduced as full contact does not occur until later in the swing. This effect can be pronounced for larger chip sizes.

One further possible contributor to inconsistent results and also to a large number of swings required is the tendency for larger aggregates to twist the slider out of the horizontal plane during a test. While this should not affect the value of that swing, unless the slider is returned to its horizontal position before the next swing, the subsequent swing could impact the out-of-plane slider into the surface rather than allow it to skid across the surface. This may also cause earlier contact with the test surface than allowed for.

### 5.1.4 Kick Back and Bucking of BPT on Larger Aggregates

An analysis of the individual BPT tests on each test surface does not support the view that kick back and bucking of the instrument occurs when the slider contacts these larger aggregates.

The test method of TRRL Roadnote 27 (1969) requires that five successive readings do not differ by more than 3 BPN. If the range is greater than this, the swings are repeated until the successive readings are constant. If kick back and bucking occurred, it would be difficult to obtain such close agreement between successive swings of the pendulum.

Table 5.1 shows that between five and eight swings is the usual number required for a valid test. Also, a pronounced tendency for particular laboratories to occasionally take a large number of swings to attain a valid test can be seen. This tendency may reflect particular care taken by the operator, whereas other operators may be more inclined to approximate the reading in these situations.

However, the tests with these large number of swings were not made exclusively on the larger aggregates where, perhaps, kick back and bucking may be expected to occur. Table 5.1 shows that they were carried out on small chip sizes or smoother asphaltic concrete surfaces as well.

## 5.2 Effects of Local Practices

Local variations in practice could influence repeatabilities. For most of the chipseal surfaces, repeatabilities have accounted for 60-80% of the reproducibility. In requesting the laboratories to carry out the measurements, emphasis was given for them to use their normal practice even if this was a deviation from TRRL Roadnote 27 (1969). For example, one laboratory, rather than adjusting the zero, does a "zero reading" and subtracts this from the subsequent readings. Another laboratory sprays the surface with a mist of water from a hand garden sprayer rather than flooding the surface from a bottle or beaker of water.

Such practices influence the results as research for pedestrian tiled areas has shown that 95% of the change in BPN from the dry to the wet condition reading occurred after the first light misting, and little further decrease in skid resistance occurred after that. Flooding the surface slightly increased the BPN reading (by 2 BPN) (i.e. increased skid resistance), because the excess water provided a resistance to the swing.

The purpose of including current local practice in the study was to ensure that the findings could be matched to field measurements accumulated so far (1996) at the laboratories.

Table 5.1 Number of swings to attain a reported British Pendulum test.

| Test surface description | Laboratory ID No. | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | |
| | 1st | 2nd | 1st | 2nd | 1st | 2nd | 1st | 2nd | 1st | 2nd | 1st | 2nd | 1st | 2nd | 1st | 2nd |
| 1. Asphaltic concrete | 5 | 5 | 5 | 5 | 5 | 5 | 5* | 5* | 5 | 5 | 6 | 8 | 5 | 5 | 6 | 8 |
| 2. Grade 2 hand-placed | 5 | 5 | 5 | 5 | 5 | 29 | 5 | 5* | 5 | 6 | 5 | 6 | 5 | 5 | 10 | 5 |
| 3. Grade 2 random | 3** | 5 | 5 | 5 | 5 | 5 | 5* | 5* | 5 | 7 | 5 | 12 | 5 | 5 | 16 | 8 |
| 4. Grade 3 chip | 5 | 5 | 5 | 5 | 5 | 8 | 5* | 5* | 5 | 6 | 5 | 23 | 5 | 5 | 7 | 7 |
| 5. Grade 4 chip | 5 | 3** | 5* | 5 | 8 | 16 | 5* | 5* | 5 | 8 | 10 | 6 | 5 | 5 | 18 | 6 |
| 6. Grade 5 chip | 4** | 3** | 5 | 5 | 5 | 5 | 5 | 5* | 6 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 7. Grade 6 chip | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 8 | 5 | 5 | 7 | 5 | 5 | 8 | 10 |
| 8. Friction course | 4** | 3** | 5 | 5 | 5 | 5 | 10* | 10* | Not tested | | 5 | 5 | 5 | 5 | 8 | 22 |

* Reported by testing laboratory as valid test, but variation of BPN means does not comply with requirements.
** Insufficient swings but three consecutive swings of the same Pendulum number were recorded.
\+ Because of a timing irregularity, Laboratory 5 was excluded from this section of the trial.
1st, 2nd Test runs.

Reproducibility could be improved by, for example ensuring a greater standardisation of technique, and calibration of the BPT immediately before making the measurements. However, because repeatability is such a large contributor to reproducibility, the gains by such measures are likely to be no more than about 10 to 25% of the reproducibilities of this study, unless repeatability could also be reduced by additional measures.

## 5.3 Effects of Operator Training

Phase 3 of this study, in which two operators standardised their full technique (including those procedures not set out in TRRL Roadnote 27 (1969), reduced repeatability significantly, and the two operators were then statistically indistinguishable. True reproducibility is a result of consistency between different laboratories with different personnel and different instruments. However if the two operators had been considered as if they were separate laboratories, very significant improvements in reproducibility were obtained.

Operator training would appear then to be the most effective avenue in improving the precision of the BPT. The first stage would be to ensure adherence to the practice of TRRL Roadnote 27 (1969), then to include the additional steps not covered in that Roadnote, such as setting the slider contact distance, setting the zero, levelling the slider after each swing, and using similar amounts of water.

For road surface assessment, there is a need to account for wind. In other than calm or light wind conditions the instrument is sensitive to wind speed and direction, relative to the direction of swing.

## 5.4 Use of ASTM E770-80 for Road Surface Assessment

The standard ASTM E770-80 (ASTM 1980) has been developed for typical pavement surface construction methods used in the US which differ significantly in one or two practices from the road surface construction methods used in New Zealand.

At least one aspect of the ASTM appraisal method requires some interpretation when applying it to New Zealand road surfaces. This aspect is that common US chipseal pavement surfaces incorporate a mix of chip sizes, whereas in New Zealand the practice is to use a single sized chip.

This difference in sealing practice affects the parameter F of ASTM E770-80 which is directly related to the microtexture quality of the surface of the matrix binding the macrotexture, i.e. to the larger stones of the chipseal. In New Zealand this matrix is usually the bitumen. Its properties and associated parameter numbers will therefore be consistent regardless of the road surface under scrutiny.

The texture parameter table (Table 3.3 in this report) shows that parameter F exhibits some variability, because the matrix in the test surfaces consists of the epoxy used as a binder. The classification for this matrix would be F-2: ... *a smooth matrix with a visible texture that is not distinct enough to permit a visual height estimate* .... But in the areas where the epoxy was spread so thinly that a cavity or undrained area formed below the drainage invert level, this can be classified as F-0 according to ASTM E770-80.

Because the chips were in a flooded condition for each skid resistance test, this cavity or undrained area may affect the final BPN because of its ability to retain water. The variation seen in Table 3.3 is therefore the result of averaging the parameter F results which are either 2 or 0.

The main advantage of employing the methods of texture classification as outlined in ASTM E770-80 is that they ensure a closer study of the surface texture than could otherwise be made. The area of road surface examined for the ASTM E770-80 method is similar in size to the area contacted by the BPT slider, both being very small relative to the total surface. This enables the area directly in the path of the BPT slider to be studied, with very little influence from the surrounding areas outside this specific zone.

## 5.5 Recommended Road Surface Assessment Method

The method for assessing a road surface as determined by the BPN is as follows:

1. Select the road length of interest and divide it into segments of not more than 50 m length. The segment should be uniform and not include joins between two types of seal. If patches are present, the skid resistance of these may be measured, if desired, but should be separately averaged.

2. Identify the wheelpaths and divide the segment into the four zones of:
   - left hand shoulder
   - left hand wheeltrack (outer wheeltrack)
   - between wheeltracks
   - right hand wheeltrack adjacent the centreline (inner wheeltrack)

   where left and right are assigned with respect to the traffic flow in the zone.

3. To determine the minimum skid resistance of the lane segment, proceed through the following steps (4) to (6) using the right hand wheeltrack zone, i.e. the wheeltrack adjacent the centreline, as the zone for measurement. Measurements can be made in both wheeltracks if desired.

4. Mark out five positions along the zone. These may be at spacings of between approximately 5-15 m but should cover the length of the zone.

5. Measure the skid resistance as BPN:
   - on longitudinal sections, make the measurements in the direction of the traffic;

   - if measuring on a curve, measure in a radial direction away from centre of curvature;

   - if the curve is cambered, ensure that the base of the instrument is horizontal.

6. Determine the mean BPN for the five positions. Determine the mean BPN for any patches and other non-uniform areas separately.

7. Determine the variation in skid resistance over the site, following steps (1), (2), (4), (5) and (6) but make the measurements in each zone. Report the results for each zone separately.

## 6. CONCLUSIONS

- The study has confirmed that wide margins of repeatability and reproducibility of measurements occur when using the BPT on most New Zealand road surfaces.

  The pattern is for good repeatability (4-8 BPN) for measurements on asphaltic concrete and friction course; moderate repeatability (10-11 BPN) on fine chipseal surfaces (grade 6); and poor repeatability (16-34 BPN) on the larger chipseal surfaces (grades 2-4). This pattern was sustained in general for material from four quarries, but with some variation for individual quarries.

  The pattern of BPN rising to a maximum for grade 4 chip and declining for chip sizes both larger and smaller, that had been found for one quarry, was not sustained for material from the three other quarries.

- Reproducibility is always poor, being 20-35 BPN for all surfaces tested.

- The poor repeatability would appear to arise from a combination of:
  - the relatively small size of the area sampled by the instrument compared to the irregular nature of the surface;

  - the irregular nature of the surface being tested, making placement of instrument and setup of slider contact distance difficult;

  - the need for operator refinements additional to those set out in TRRL Roadnote 27 (1969).

- Once set up, the BPT can quickly give a stable measurement between successive swings on most occasions.

  Occasionally many swings are needed for a valid measure and this appears to arise from the irregular surface making setup difficult or making the slider twist out of plane during tests.

- The study shows evidence of systematic error between laboratories and that some laboratories do not follow, in full, the measurement method described in TRRL Roadnote 27 (1969), particularly for the required number of swings.

  The large repeatabilities obtained on most chipseals, however, mean that steps to reduce these systematic errors will reduce reproducibilities only by about 10-25%. Further improvement will only be possible if repeatability is improved.

- Training of two operators at one laboratory so that they both used identical fine detail in their measurement method appeared to give significantly improved repeatability and, if this approach was conducted with other operators, substantial improvements in reproducibility may be obtained.

- The technique detailed in ASTM E770-80, of closely examining the road surface and ascribing parameters to the sealing chip macro- and microtexture, appeared to be an effective method for understanding the nature of a road surface. However, although an equation linking these ASTM E770-80 parameters to measured BPN was derived, the significance of this relationship was that of an indicative trend only.

- Detailed measurements on the road segment showed that a road surface could be clearly separated into trafficked and untrafficked areas, i.e. wheelpaths and shoulders.

  Over a 50 m road segment the BPN appears to fluctuate randomly within a range of BPN values. This range was relatively narrow (5-6 BPN) for smooth surfaces such as asphalt, but widens for increasing texture size, as follows:

| **Road surface** | **BPN range** |
|---|---|
| Asphalt | 5-6 |
| Friction course | 9-10 |
| Grade 5 chipseal | 11-12 |
| Grade 3 chipseal | 13-14 |

- On curves the BPN is less in a radial direction than in the longitudinal direction, i.e. along the wheelpath of the traffic. This reduction in BPN is statistically significant but only to a moderate level of significance. The BPN is often, though not always, lowest in the wheelpath closest to the centreline.

## 7. RECOMMENDATION

Further work, if undertaken, could seek to improve both repeatability and reproducibility by training operators and by providing methods to ensure that the instrument is accurately adjusted.

## 8. REFERENCES


ASTM (American Society for Testing Materials). 1980. Standard test methods for classifying pavement surface textures. *ASTM E770-80.*

ASTM. 1992. Standard practice for conducting an inter-laboratory study to determine the precision of a test method. *ASTM E691-92.*

ASTM. 1993. Surface frictional properties using the British Pendulum Tester. *ASTM E303-93.*

Dravitzki, V.K., Potter, S.M., Ball, G.F.A. 1992. Guidelines for assessing the potential slip hazard of pedestrian surfaces. *Central Laboratories Report 92-27124*, Works Consultancy Services, Lower Hutt.

Oliver, J.W.H., Witt, H.P. 1978. Detailed procedures for calibration of the British portable skid resistance tester. *Australian Road Research Board Technical Manual ATM No. 6.*

Transit New Zealand 1993. *Bituminous sealing manual.* Transit New Zealand, Wellington, New Zealand. ISBN 0-478-04107-1.

TRRL (Transport and Road Research Laboratory). 1969. A guide to the structural design of flexible and rigid pavements for new roads. *TRRL Roadnote No. 27*, 2nd edition, ISBN 11 550060X. Crowthorne, England.