Road Surfaces &
Loss of Skid Resistance
caused by Frost & Thin Ice
in New Zealand

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Road Surfaces & Loss of Skid Resistance caused by Frost & Thin Ice in New Zealand

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Executive Summary

Introduction

This study was undertaken in 2001-02 to identify if the road surface types used in New Zealand that have good skid resistance properties in the wet, would retain them in conditions of frost or thin ice in New Zealand winters.

The research was laboratory based. Frost and ice were formed on samples of road surfaces within controlled climate rooms normally used for forming ice and frost on plants.

Skid resistance properties were assessed using the British Pendulum Tester (BPT) and the macrotexture was assessed using a stationary laser profilometer (SLP).

Road surfaces tested comprised dense and open-graded asphalts, grooved dense asphalt, grades 3, 4, and 5 chipseals, as well as two-coat seals. Samples were taken from the wheeltrack and non-wheeltrack regions of the road to provide a range of microtexture.

Light frost (i.e. traces), medium frost (about 50% cover) and ice film conditions (100% cover) were formed on the samples, which were then tested for skid resistance.

To assist interpretation of the findings, the same samples were placed in the open and tested after a natural frost had formed on them.

Further interpretations were developed by inspecting a range of roads in the Wellington and Wairarapa regions, North Island, New Zealand, over a frosty period to observe how frost formed over the road, and to confirm that the effects on skid resistance, noted in the laboratory tests, were similar to those in the field.

A further part of the study examined the 'temperature correction' that must be applied to the BPT by undertaking control tests in the controlled climate rooms using ceramic tiles as substrates, and testing over the range −2°C to 30°C.

Conclusions

The main conclusions of the study are as follows:

- Frost first forms on chipseal on the tips of the chips, then spreads over the chips and bitumen layer as the frost intensifies. In general this frost is only loosely adhered to the chips.

- Because frost forms this way, the effect of macrotexture in maintaining skid resistance in these conditions appears to be small from this study. The effect of macrotexture under weighted rotating tyres may be greater.

- Macrotexture shows only a small effect in maintaining skid resistance when thin ice layers are present. This ice is tightly adhered to the chip, and therefore it is expected to represent the on-road situation.

- Smooth surfaces appear to be very vulnerable to the effects of frost and ice, i.e. have low skid resistance, because the ice covers the entire surface, and it cannot be easily displaced into the voids between the chips.

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- The loss of skid resistance is great, being 30% to 60% of the wet skid resistance value. This loss is significant for road management as it makes policies providing higher skid-resistant surfaces for higher risk road sections difficult to achieve for frost or ice conditions.

- The influence of microtexture is unclear. With some road surface types those samples that had higher skid resistance in the wet condition (which indicates a more harsh microtexture) also had higher skid resistance in the frost or ice conditions. However the pattern is inconsistent.

- The study shows a small improvement in ability to retain skid resistance for surfaces that have a macrotexture greater than 1.5 mm (measured as MPD).

- In this study, locations where frost or ice can be expected appear to be stretches that are shaded from the sun for all or most of the day. These locations are readily (and cheaply) identified by visual inspection, but thermal mapping would be a more rigorous method.

- Using the BPT at less than 5°C raises uncertainties. Although this study has identified them, it has not resolved them. These uncertainties relate to the effect of the recorded friction on a surface increasing as the temperature decreases. The relationship between friction measurement and temperature below 5°C was found to be inconsistent.

- The controlled climate rooms used in this research to examine the effect of frost on roads, do not provide conditions comparable to natural conditions. However, they are adequate for examining the effects of ice on road surfaces, and the effects of low temperature on methods of measurement.

Recommendations

- A lower limit of about 1.5 mm macrotexture is suggested. However, because the effectiveness of macrotexture on skid resistance is not reliable, additional strategies are suggested for managing frost and light ice conditions in mild or moderate New Zealand winter conditions. An example is the use of CMA.

- If the BPT is to be used at low temperatures (e.g. below 5°C) for measuring skid resistance, then additional research is needed to reliably identify the friction–temperature relationship.

- Future studies of the relationship of skid resistance and road texture under frost and ice conditions should use measurement procedures that are more responsive to macrotexture. Examples are the use of the GripTester or of instrumented vehicles which have weighted tyres.

Abstract

The effects of frost and ice on the skid resistance of a range of road surface types used in New Zealand were examined in a laboratory-based study, carried out in 2001-02. Frost and ice were formed on samples in controlled climate test rooms. In addition the same range of road samples was exposed to natural frost. Road surface types tested included dense and open-graded asphalts, and both fine and coarse textured chipseals. Comparisons were made with actual roads in frost conditions. Fine textured road surfaces were found to be very vulnerable to loss of skid resistance in frost and ice conditions. Coarse textured surfaces appeared to retain more of their skid resistance in frost and ice although the increase in skid resistance is small. The implications for road management are examined.

Additional work examined the corrections that should be made to skid resistance results to allow for the effects of very low temperatures (<5°C) on the methods of measurement.

1.   Introduction

1.1   Purpose

The purpose of this project, undertaken in 2001-02, was to identify the road surface types used in New Zealand that counteract the effects of frost and thin ice on reducing skid resistance. These surface types could then be used on the many scattered and short stretches of road subject to frost or thin ice, thereby improving the safety of New Zealand roads in winter.

This research is not expected to be relevant to a number of roads in New Zealand that traverse semi-alpine or cold areas, and experience severe winter conditions. As these roads are the subject of special winter maintenance procedures, they were not the focus of this study.

1.2   Background

In many regions in New Zealand, frost and ice on roads, while not widespread, can occur both discontinuously in many short stretches of road, and infrequently in winter. As a consequence this frost and ice can pose a significant hazard to motorists because it is unexpected. The number and distribution of these areas are such that treatment by sophisticated systems such as sensors and ice warning systems, as outlined in *Road Weather Information Systems* by Dravitzki & Varoy (1997a) are not practical.

A previous Transit New Zealand Research Project PR3-0055(b), *Ice and Its Effect on Skid Resistance of New Zealand Roads*, undertook a review of the ice hazard of New Zealand roads. This included a review of the international literature on the causes of ice formation and the means to counteract these hazards. This review found that many influences affected the formation of ice on roads. Some were regional such as location and climate. However, many were highly location-specific such as: shading which influences radiation gain or loss; road surface type; the nature of the basecourse and subgrades; and the moisture content of these layers.

The literature also showed that the road surface could be highly effective in limiting the loss of friction from ice and frost. Report No. 309 of the Swedish Road Research Institute (VTI 1986) field-trialled 20 surfaces over a four-year period. In that project road surfaces were tested over a number of days when adverse conditions were present. These conditions changed over those days and included snow, sleet, ice and frost.

In mild winter conditions, e.g. with frost, thin ice, or loose snow, some surfaces had markedly higher skid resistances. These tended to be surfaces that had good drainage capability and texture, such as chipseal or open-graded asphalt.

In severe winter conditions, e.g. with compacted snow, thick ice and sleet, the surface had little impact on skid resistance, although differences in the rates of recovery after the application of de-icing salts were evident.

Surface effects seemed to be less pronounced as the trial progressed, but surface wear appeared to be severe (most likely related to both the use of studded car tyres that are allowed in Sweden in winter, and the gritting of roads).

From a New Zealand perspective, the VTI Report 309 is a useful starting point as it indicates which surface types could counteract the effects of frost and thin ice. However work specific to New Zealand is needed to identify the extent that road surface types in New Zealand exhibit similar abilities to counteract the effect of frost and thin ice. This research is the subject of this report.

VTI Report 216A (1981) is also useful as it provides background to the formation of frost and ice on roads, and on the influence that the road structure has on the tendency for frost and ice to form on the road surface.

A further body of literature addresses some complex issues such as how weather conditions can influence the structure and surface of thick road ice, and how this in turn can influence the friction interaction with vehicle tyres. However, this literature describes road conditions which occur only rarely, if at all, in New Zealand and so it was not considered further.

## 2.	Formation of Frost & Thin Ice

VTI Report No 216A (1981), *Road Icing on Different Pavement Structures,* identified three categories of winter condition on roads. They are:

1. Hoar Frost (white frost)
2. Ice
   - thick ice
   - ice glaze (thin ice)
   - ground icing
3. Snow
   - loose snow
   - compacted snow
   - slush
   - sleet

Of these conditions, hoar frost and ice glaze are relevant to this current Transfund study. VTI Report 216A describes the formation of these conditions in detail, and is summarised as follows.

- *Hoar frost* (white frost) forms when the temperature of the road is both less than 0°C and less than the dew point of the air immediately above. The dew point is the temperature where the water-holding capacity of the air is at its limit, i.e. its relative humidity is 100%. For example, air at 1°C and 90% relative humidity would have to cool to −1°C, i.e. its dew point, for the relative humidity to increase to 100%. Likewise the dew point for air at 1°C and 50% relative humidity will be −8°C.

Frost can form in three main types of weather:
- clear calm nights when radiative cooling rapidly cools the road but the air is close to 0°C;
- after a cold clear night when the rising sun causes air circulation and moist air moves over the already cold road;
- after a cold but cloudy night, the sky clears and the road rapidly cools but the air is still moist.

All these factors are relevant to New Zealand but the first two are the most common.

- *Thin ice* (ice glaze) is a layer of ice that coats the macrotexture of the road. VTI Report 216A describes this condition resulting from:

- super-cooled rain landing on a road surface that is close to 0°C, where it instantly freezes;
- light rain on a road surface which is already less than 0°C, where it quickly freezes;
- moisture on a cooling road from earlier dew or light rain, which then freezes when the road cools to below 0°C;
- frost or light snow compacted by trafficking.

For the non-alpine areas of New Zealand, the last two conditions will be the more common causes of ice on the roads.

While frost and ice conditions obviously exist when the temperature of the road is about 0°C or less, the conditions which allow the road to reach this temperature are much more complex. VTI Report 216A examines these conditions in detail. The thermal properties of the road surface and base layers influence its heat-storage properties. At night time the road is warmer than the adjacent land because the heat stored in the road is greater and there is a steady flow of heat from its sublayers to the road surface.

The terrain and adjacent vegetation influence the exposure of the road to heating by the sun in the daytime. Frost or ice is invariably less likely to form on a road exposed to sun compared to the adjacent land, whereas areas shaded from the sun all day will have no reservoir of heat and will be prone to frost or ice formation.

3.   Laboratory Methods of Frost Formation

3.1   Laboratory Set-up

Field-based studies of the influence of road surface parameters on skid resistance in frost or ice conditions are difficult to carry out. Variations in the weather conditions give uncertainties in the degree of frostiness being reproduced. This was evident in VTI Report 309 (1986). In addition, studies must wait for suitable weather, and safety issues arise when testing on roads under marginal conditions. Laboratory-based studies are an alternative but need to be able to reproduce realistic frost conditions.

The National Climate Laboratories operated by Hortresearch at Palmerston North, New Zealand, have controlled climate test rooms that are often used for reproducing cold conditions. Each room is approximately 3 x 3 x 3m in size, and has full micro-processor programming and control capability to allow temperature and humidity to be controlled to ±0.5°C over a range of –25°C to 48°C, and humidity to ±3% over a range of 10% RH to 95%RH respectively.

A common use for the Climate Laboratory is to test the resistance of plants to frosts, both with respect to the cold itself and also to accumulations of frost crystals. The frost formed in these test rooms is different from a frost formed outdoors, because it is not possible to incorporate the radiative cooling effect that will occur outdoors on clear still nights. For the usual work on plants, extrapolations, based on accumulated experience of indoor conditions to outdoor conditions, need to be made.

The size of the test room is large enough to accommodate road samples and an operator using a British Pendulum Tester (BPT). These test rooms were used for this laboratory-based study on the interaction between skid resistance of road surfaces and frost or ice conditions and, as for plant work, correlations were made with conditions that occur outdoors.

3.2   Selecting Road Surface Test Pieces

Road surface test pieces selected for testing included a range of both macro- and microtexture. The road surfaces were:

- Open Graded Porous Asphalt (OGPA)
- Asphaltic Concrete
- Grooved Asphaltic Concrete
- Chipseals - Grade 5
          - Grade 4
          - Grade 3
          - Grade3/4 Two Coat
          - Grade 5/6 Two Coat

Microtexture was varied by taking samples from the wheeltrack and from outside the wheeltrack. With trafficking, some polishing of the microtexture will occur so that the samples from the wheeltrack (wheeltracks WT1 and WT2) should have a reduced microtexture relative to the samples taken from outside the wheeltrack (non-wheeltrack NWT1 and NWT2).

Samples were cut from the road as 300 mm-diameter circular cores. Test pieces measuring 300 mm x 150 mm were cut from these cores, then mounted on ceramic tiles to provide stable test pieces. A typical sample is shown in Figure 3.1.
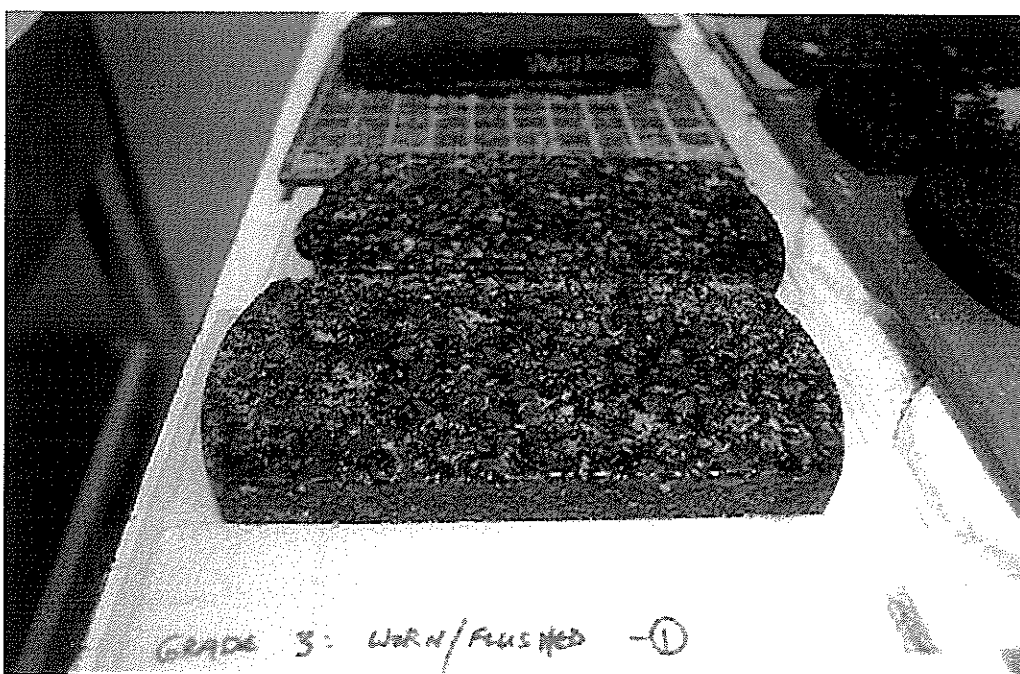

Figure 3.1   Road samples prepared for laboratory tests.

3.3   Texture Measurements

The textures of the road surface test pieces were measured with Transit New Zealand's stationary laser profiler (SLP). This instrument enables surface heights to be measured to within an accuracy of 0.03 mm over a wavelength range of 0.63 mm to 500 mm (Cenek et al. 1997). The SLP calculates mean profile depth (MPD) to ISO Standard 13473-1 (1977): *Characterisation of pavement texture utilising surface profiles.*

3.4   Skid Resistance Tests in Frost Conditions

Frost was formed on the samples by placing them within the test room that was to be operated at –2°C to –4°C and at a high relative humidity around 95%.

Frost crystals formed over the surfaces of the road surface test pieces. For light frost conditions, only a scattering of crystals formed, while for medium frost conditions the layer was much more dense but still constituted a single layer of crystals only.

Ice conditions were simulated by wetting the already cold samples with a water spray, so that the wet surface quickly turned to ice in the cold conditions. This simulates one of the mechanisms for forming an ice glaze, described in Chapter 2 of this report.

Samples were tested for skid resistance using the BPT. For this testing no water was used, so that the skid resistance measured is solely the effect of frost crystals over the road surface. In addition, the samples were tested at room temperature when wetted with water, to define the skid resistance of the road samples in their more normal condition of wet surfaces.

After observations had been made of natural frost formation on roads, the laboratory-based work was extended to determine the effect of a natural frost on the road samples. Although it is usually difficult to study frost over a range of road surfaces at the same time, this could be done using the same road test pieces that had been used in the laboratory tests. By wetting the test pieces and locating them in a sheltered field on a clear winter evening, a natural frost would form on them.

The skid resistance of these test pieces was determined using the BPT in the early morning after frost had formed.

3.5   Temperature Corrections for BPT Measurements

A set of corrections to the BPT measurements made at different temperatures are included in TRRL Road Note No. 27 (1969). This publication provides a graph of temperature corrections to apply to measurements taken at temperatures between 0°C and 40°C. These temperature corrections are made to all BPT measurements to adjust the readings to those which would have been obtained if measurements had been taken at 20°C. They are needed for making comparisons from separate test runs.

This scale of corrections in Road Note 27 indicates a correction of 7 BPN (British Pendulum Number) for 0°C. However, work that was being carried out on a related project for Transit New Zealand on the influence of CMA (Calcium Magnesium Acetate, a de-icing salt) on skid resistance, raised uncertainty as to the accuracy of these Road Note 27 corrections.

The trials with CMA had indicated corrections of 12 or 14 BPN could be in order. Therefore additional work was undertaken to better understand the effects of testing for skid resistance at low temperatures, and to better identify the adjustments that need to be made for temperature effects.

3.6   BPT Tests at –2°C

Previous work (Dravitzki et al. 1997b) has shown that the repeatability on testing roading samples could be 4 to 10 BPN, but on a smoother substrate the repeatability could be within ±1 BPN. Therefore, for this current work, ceramic paving tiles were used as the test substrates. The tiles chosen ranged in macrotexture from nil to tiles with a profile of 2 mm from highest to lowest points.

Testing was carried out over the temperature range of −2°C to 30°C in the controlled climate rooms, and with humidity in one room controlled at 50%, and in the other at 90%.

Separate BPT instruments were left in each room as the humidity and temperature conditions were altered. Each temperature step took about 30 minutes to establish and the tester was allowed to come to equilibrium in these conditions.

A further variation was to use a third BPT, but it was taken in and out of the test room and allowed only 10 minutes to adjust from normal room temperature to the temperature of the test room. This simulated the more normal testing process in the field, where a tester will be taken from a warm vehicle and set up in about 5-10 minutes for use on the road.

4.   Field Observations of Frost Formation

Before examining the results of the laboratory testing, observations of natural frost formation on roads were obtained to help understand the laboratory test results.

In late May–early June 2001 weather conditions in the lower North Island were cold, but with clear still nights leading to a series of medium to heavy frosts in the region. The opportunity was taken to observe the frost formation on a road and to note characteristics of sites at which the frost had formed. Because the frost conditions were quite severe over most of the region, light frost also formed in areas where frost occurrence was usually rare. By examining the frost on the roads in these areas as well as those where it was dense, information was obtained of how frost progressively built up on the road surface.

4.1   Formation of Frost on Roads

Several sites showed a gradation in the extent of frost from one side of the road to the other. On chipseal, frost was noted to form first on the tips of the chip, but not on the bitumen layer at the base of the chip. The frost occurs on the tips of the chips first because, with radiative coding of the road, they are cooler than the bituminous layer of the seal. The frost is of small granular crystals, forming first as a single layer over the chips. The crystals adhere only loosely to the chips and are easily removed.

As the frost becomes more intense it forms a continuous layer over the chip and bituminous binder, and as it becomes even more intense, several layers of frost crystals form. All these crystals are only loosely bound and are easily removed. For example trafficking can dislodge many of the tips off the chips, so that the vehicle path along the road is readily apparent.

Frost on smooth surfaces such as asphaltic concrete forms in a similar way except that the frost forms quite uniformly over the surface. Because it has finer texture, the initial stage of frost forming on the tips of the chips (as for chipseal) is less prevalent on asphaltic concrete.

4.2   Locations of Frost on Roads

The VTI 309 report (1986) listed a number of factors which influenced the formation of frost on the roads in Sweden, and which include: the depth of the road layers, the degree of moisture in the base layers; the thermal properties of the layers; and the extent of shading of the road.

Observations made in May–June 2001 in the Wellington region during a prolonged frosty period showed, however, that the single most important factor seemed to be the shading of the road by terrain or by vegetation. Frost appeared to form exclusively at sites where the road was not exposed to the sun for any part of the day, or where exposure, if it did occur, was very brief, e.g. 5 to 30 minutes.

At these sites, a heavy dew could form in the early evening even if nearby areas were reasonably dry. Frost would then form overnight or early morning. Further, because these locations were not exposed to the sun, frost once formed could remain throughout the day on the untrafficked sections. The frost could be further compounded by an additional freezing cycle in the following night.

4.3   Skid Resistance Tests on Frosted Roads

Skid resistance tests were undertaken on a frosted road which, being at the end of a cul de sac, had been undisturbed by traffic. This surface was asphaltic concrete and tests were undertaken at 6 sites, about 2 m apart within the turning area of the cul de sac. Tests were undertaken on frosted sections, and also after trafficking by a single vehicle. Tests using water to wet the surface were carried out the next day after the frost had melted.

The testing indicates that the interaction of undisturbed frost with the tester is different from that after it is disturbed. Testing with the BPT involved taking the results of a number of separate swings of the instrument to determine the surface friction expressed as BPN. For these tests the first swing of the instrument was recorded at 50 BPN. This first swing disturbed the frost and, after subsequent swings, the measurements settled to the stable readings that are shown in Table 4.1a.

Tests were also undertaken at a second site that had a Grade 4 chip surface (Table 4.1b). At this site the frost was heavy, though, by the time of measurement, the area had been trafficked and gritted. The test area was away from the main travelled section but may have been slightly trafficked, and some grit may have spread to the area.

Table 4.1   Effect of natural frost on skid resistance (BPN) measured by BPT:

a. Light frost on asphaltic concrete test surfaces.

Site	Frost undisturbed	Frost after vehicle trafficking	No frost, water wet
Asphaltic concrete			
1	50	50	80
2	36	50	81
3	41	35	80
4	38		
5	47		
6	41		

b. Heavy frost on Grade 4 chipseal test surface.

Site	Frost undisturbed	Frost after vehicle trafficking	No frost, water wet
Grade 4 chipseal	–	75	88

5.   Results of Laboratory & Field Tests

5.1   Skid Resistance Measurements

The results obtained using the BPT in the controlled climate laboratory tests and in the field are shown in Table 5.1.

Table 5.1   **Results of tests for skid resistance (measured by BPT, and expressed in BPN) and mean profile depths (measured by SLP, as MPD in mm), of the 10 test samples of road surfaces under wet, frost and ice conditions.**

Surface	Condition					MPD (mm)
	Wet	Light frost	Medium frost	Ice	Natural frost	
	Skid Resistance (BPN)					
OGPA *						
Wheel track 1	56	66	37	31	81	0.85
Wheel track 2	43	50	30	25	44	1.21
Non-wheel track 1	56	84	45	31	60	1.22
Non-wheel track 2	55	70	38	30	48	1.30
Asphaltic concrete (sample 1)						
Wheel track 1	77	68	52	24	46	0.27
Wheel track 2	76	84	42	25	40	0.35
Non-wheel track 1	77	76	50	25	41	0.50
Non-wheel track 2	79	64	64	27	41	0.41
Asphaltic concrete (sample 2)						
Test piece 1	71	67		30		0.4
Test piece 2	75	65		34		0.4
Grooved asphaltic concrete (tested along grooves)						
Wheel track 1	60	71	48	25	34	0.25
Wheel track 2	60	71	51	25	35	0.32
Non-wheel track 1	66	63	52	25	36	0.53
Non-wheel track 2	71	72	35	21	35	0.45
Grooved asphaltic concrete (tested across grooves)						
Wheel track 1	58	76	40	22	57	0.72
Non-wheel track 1	67	65	40	22	40	0.85
Grade 5 chipseal						
Wheel track 1	61	73	44	32	51	2.04
Wheel track 2	66	84	50	32	46	1.94
Non-wheel track 1	86	105	86	45	50	2.35
Non-wheel track 2	75	99	69	41	46	2.42

Surface	Condition					MPD (mm)
	Wet	Light frost	Medium frost	Ice	Natural frost	
Grade 4 chipseal						
Wheel track 1	70	105	90	36	47	2.47
Wheel track 2	68	105	85	45	44	2.54
Non-wheel track 1	70	104	85	40	40	2.86
Non-wheel track 2	75	105	90	40	58	2.65
Grade 3 chipseal						
Wheel track 1	50	51	35	25	36	0.72
Wheel track 2	49	51	37	25	36	0.78
Non-wheel track 1	67	90	62	36	46	2.18
Non-wheel track 2	65	80	49	34	45	2.05
2 coat chipseal: grade 3 / 4						
Test piece 1	69	91		70		2.96
Test piece 2	61	102		79	47	2.96
2 coat chipseal: grade 5 / 6						
Test piece 1	68	104		36	51	1.68
Test piece 2	68	107		51	50	1.68

*OGPA – Open graded porous asphalt

5.2　Temperature Correction Effects

This study showed the same trend expected if based on TRRL Road Note 27 (1969), of an inverse relationship of increased skid resistance with decrease in temperature of the test environment, road surface and slider. However there is some difference in the magnitude of the temperature correction required compared to that given in Road Note 27. In addition this study showed that, on some test surfaces, the skid resistance measurements fluctuated widely between temperatures of –2°C and 5°C. The corrections that have been calculated are shown in Table 5.2, and the supporting analysis is shown in the Appendix.

Based on these current tests, the BPN should be corrected to a room temperature reading according to a linear equation (1):

$$BPNC = 0.4193.T - 8.2515 \qquad (1)$$

where:

BPNC　=　British Pendulum Number (BPN) correction.
T　　　=　Room temperature (°C).

Note: This linear equation is valid only over the temperature range $5°C \leq T \leq 30°C$.

A quadratic equation gave no better fit to the data in comparison to the linear equation.

Figure 5.1 shows the data in comparison to that expected by TRRL Road Note 27, and that, at both high and low temperatures, a greater correction is needed. Table 5.2 shows these in tabular form.
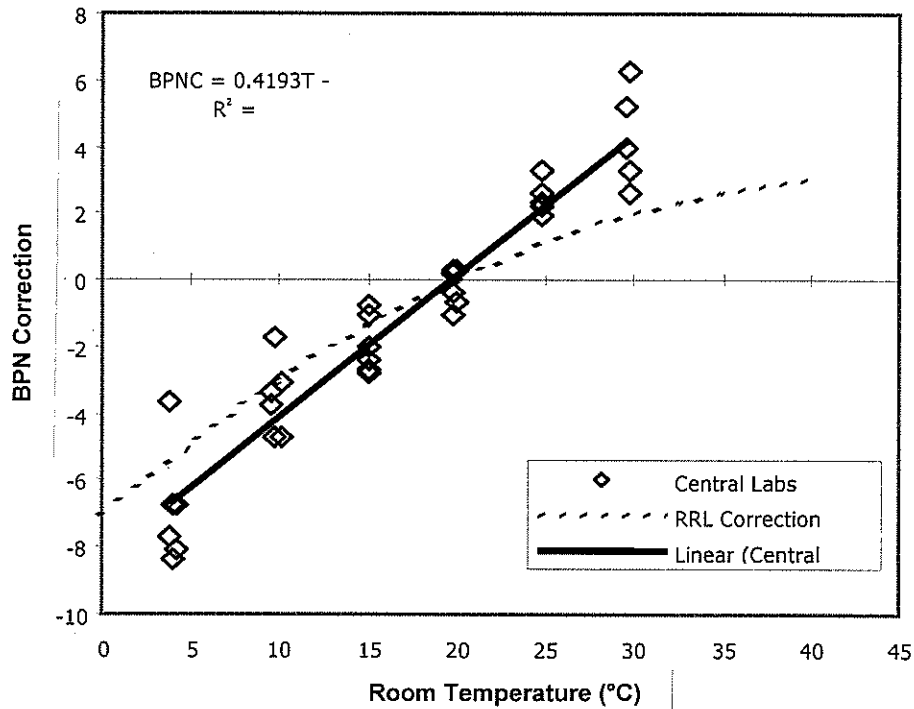
Figure 5.1   BPN correction for BPN at room temperature.

RRL = TRRL Road Note 27

Table 5.2   Recommended corrections (in BPN) for different temperatures compared to those of TRRL Road Note 27 (1969).

| Temperature (°C)	Correction (BPN) used in Road Note 27	Correction (BPN) recommended in this study
5	-5	-6
10	-3	-4
15	-1	-2
20	0	0
25	1	2
30	2	4

6. Analysis of Skid Resistance Results

The results of the skid resistance measurements, listed in Table 5.1, were analysed to determine the effects of wetness, frost and ice on road surfaces of different types.
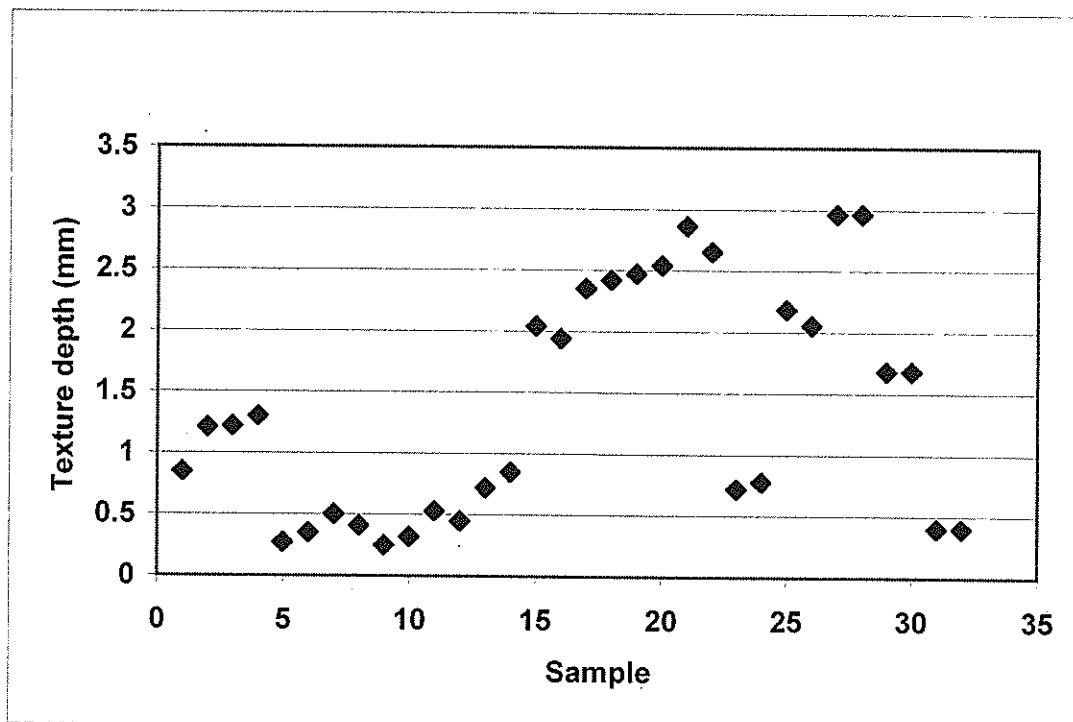
Figure 6.1 **Texture depths (mm) of the 32 samples of road surfaces.**
(Samples are grouped in order they are listed in Table 5.1)

Figure 6.1 and Table 5.1 show the spread of the mean profile depth of the 32 road surface samples tested (and listed in Table 5.1). Although the range is from 0.27 mm to 2.96 mm, Figure 6.1 shows that the textures are clustered in two subgroups, one from 0.27 mm to 0.8 mm, which are the asphalt samples, and the second from 1.6 mm to 3.0 mm, which are the chipseal samples. Figure 6.1 also displays the data in clusters of either 4 or 2 data points. These clusters show the range in the texture depth between the wheeltrack and non-wheeltrack replicates of each road surface type.

Figures 6.2 to 6.6 show the effects of the following conditions on the skid resistance of the road samples: wet only, light frost (laboratory), medium frost (laboratory), ice (laboratory), and natural frost (field).
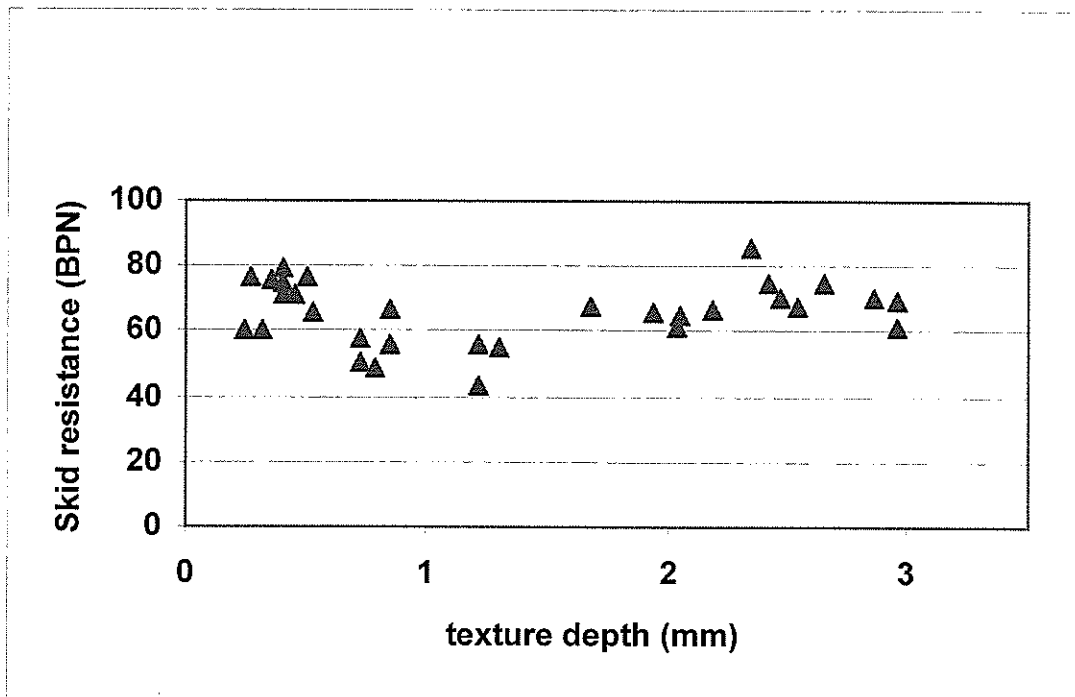
Figure 6.2   Skid resistance (in BPN) of road samples measured in wet condition versus texture depth expressed as mean profile depth (MPD, in mm).

Figure 6.2 shows that, as expected in the wet-only condition, microtexture rather than macrotexture is the main determinant of skid resistance. Even for the chipseal surfaces textures (1.5 to 3.0 mm), macrotexture is not showing any apparent significance. This is consistent both with results expected for the skid resistance tests using the BPT and from the international literature. However in practice, the macrotexture must be having some effect. On coarse chip, the area contacted by the slider is smaller than on fine chip. Microtexture will have an effect proportional to the area contacted, so if skid resistance is roughly constant with increasing texture, there must be a macrotexture effect that compensates for reduced microtexture effect.

Although Figures 6.3 and 6.4 show better skid resistance in light frost and medium frost conditions for the samples with coarser texture, this finding should be treated with some caution as it may be an effect determined by the artificial nature of the frost. In the climate laboratory frost room, frost particles form and deposit on the surface. On the coarser textured surfaces many of these can fall between the road seal chips. These samples would mirror the effect of the frost growing randomly from ice particles over the surface. However observations of a natural frost showed ice crystals starting at the high points of the chips. Figures 6.3 and 6.4 do show that the finer textured surfaces such as asphalt are affected by the presence of ice or frost.
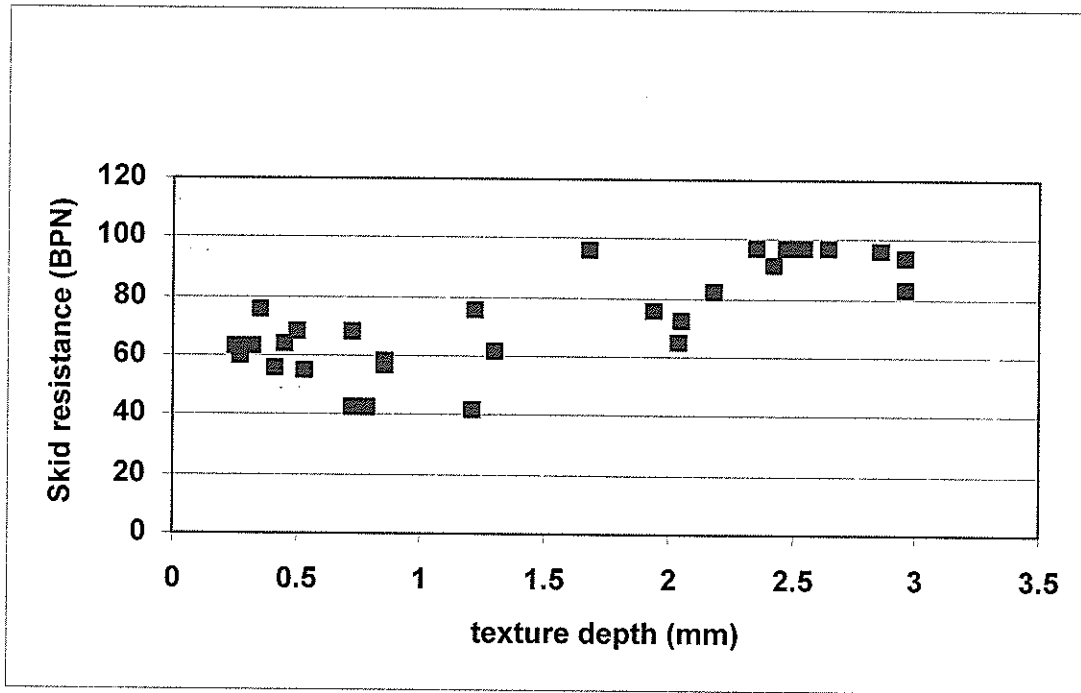
Figure 6.3 Skid resistance (in BPN) of road samples measured in light frost conditions formed in laboratory v texture depth (MPD, mm).
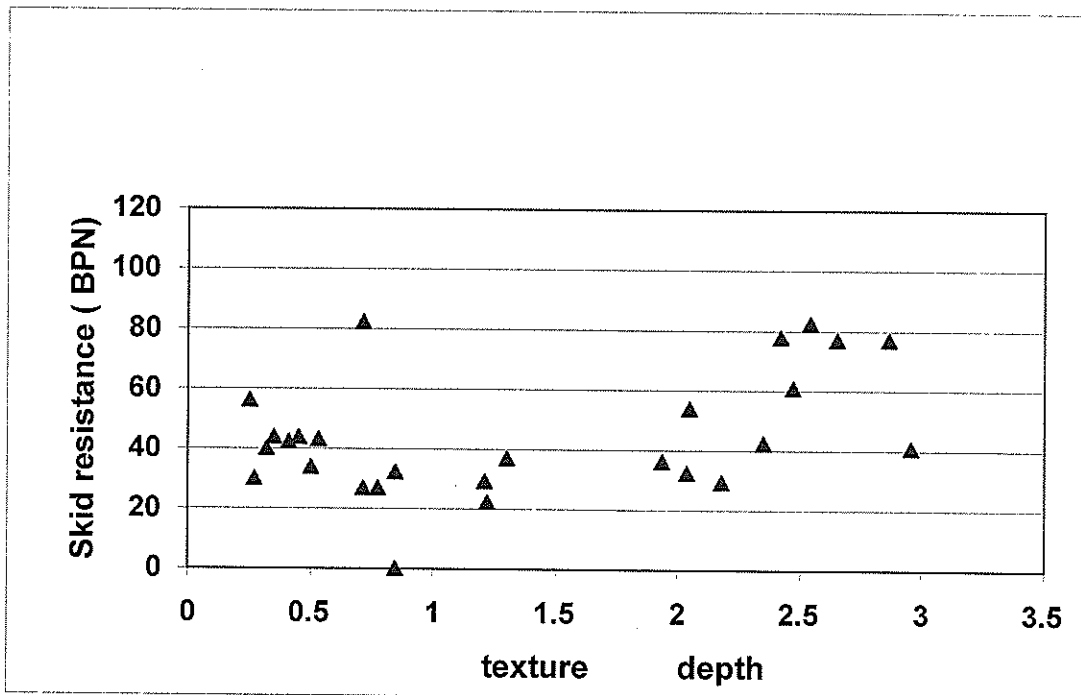

Figure 6.4 Skid resistance (in BPN) of road samples measured in medium frost condition formed in laboratory v texture depth (MPD, mm).
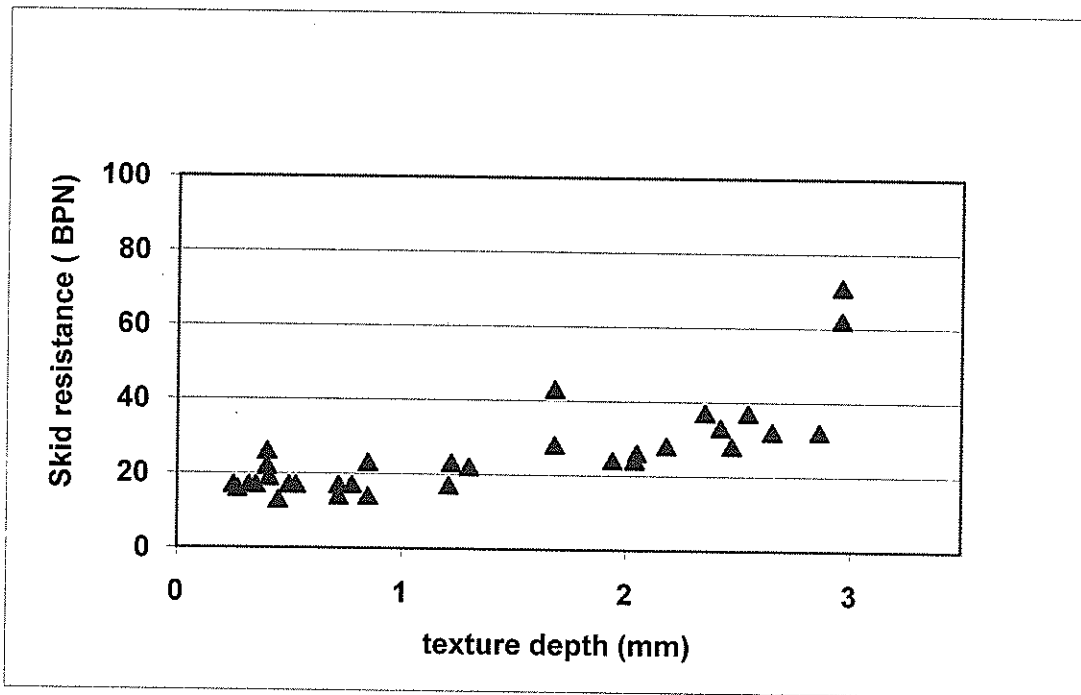
Figure 6.5   Skid resistance (in BPN) of road samples measured in ice condition formed in laboratory v texture depth (MPD, mm).
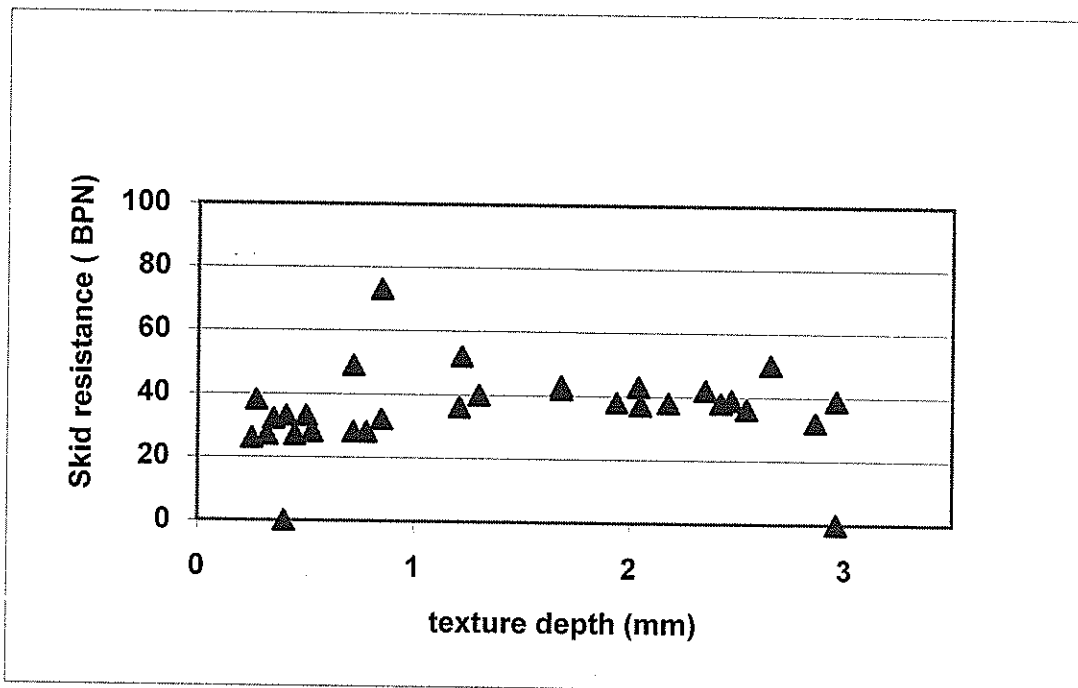

Figure 6.6   Skid resistance (in BPN) of road sample measured in natural frost formed on test samples in outdoor conditions v texture depth (MPD, mm).
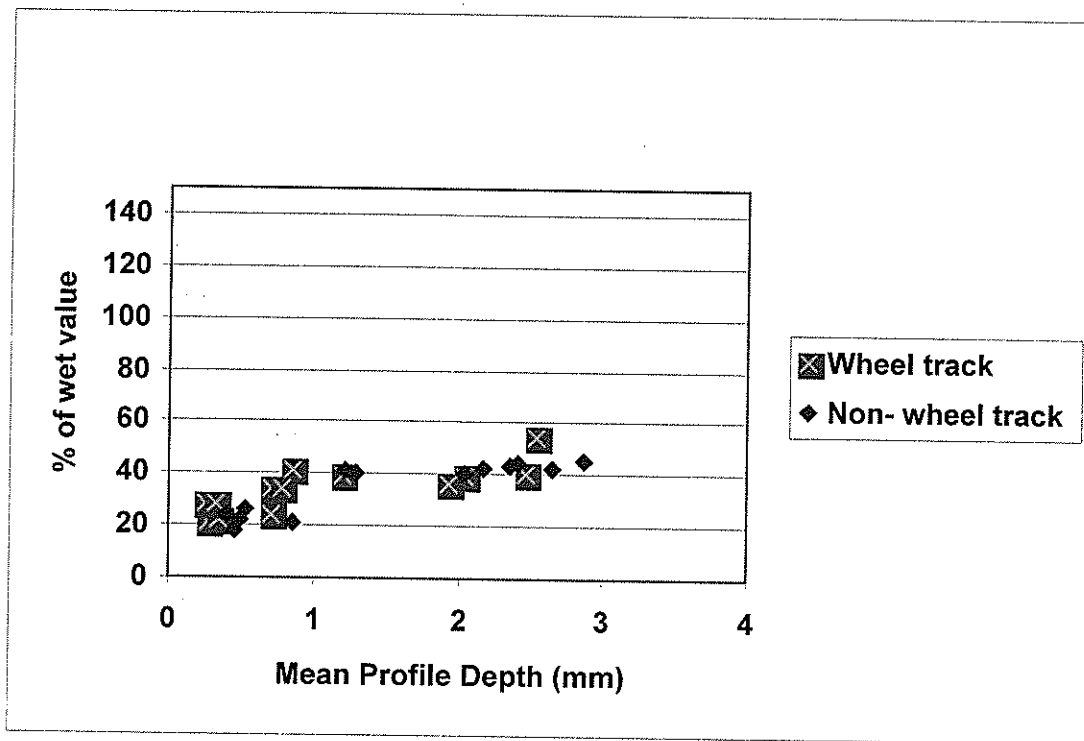
Figure 6.7   Skid resistance of road samples in natural frost conditions, expressed as percentage (%) of wet value of skid resistance v texture depth (MPD, mm).
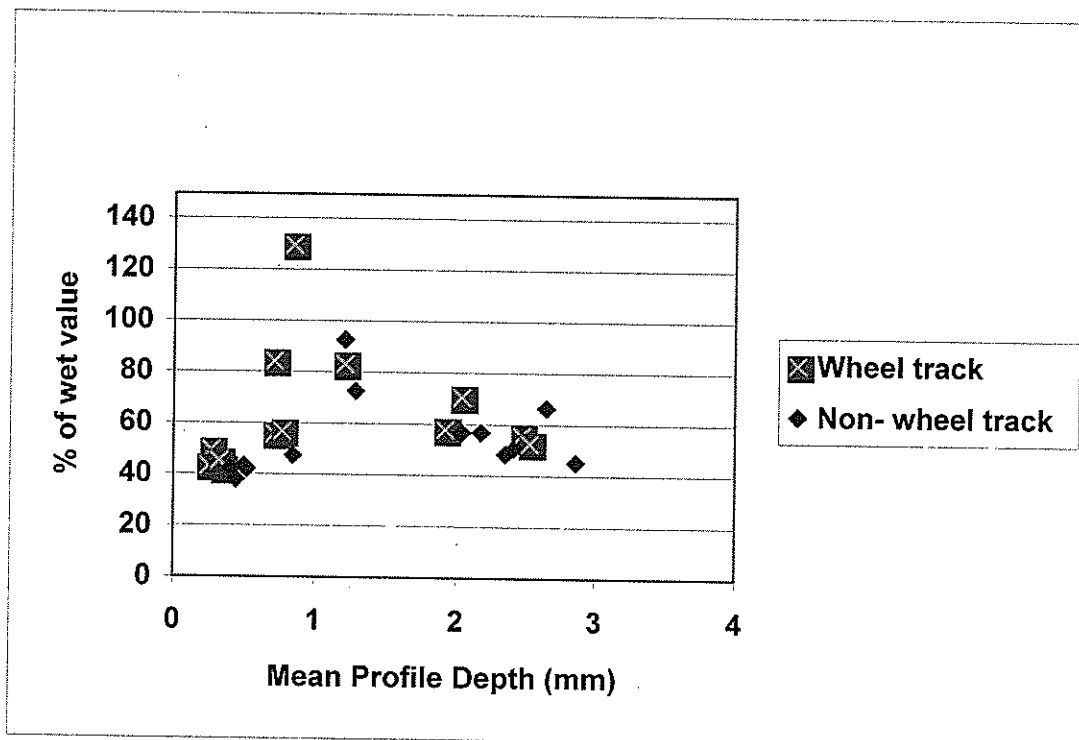

Figure 6.8   Skid resistance of road samples in ice conditions, expressed as percentage of wet value v texture depth (MPD, mm).

Figures 6.5 and 6.6 show the skid resistance in ice and natural frost conditions. Except for a few samples, the effect is very similar for both conditions. While the skid resistance is less for the ice condition, the same trend of a slight increase in skid resistance for increasing texture is evident in both figures. Also evident is that the effect of increasing macrotexture is not strong, i.e. asphalt and chipseal have similar skid resistances in these ice and natural frost conditions.

Figures 6.7 and 6.8 show the previous information in a different form. In these two figures the skid resistance in the natural frost or ice condition is expressed as a percentage of the skid resistance in the wet condition, and then plotted against texture depth. Data points are shown for both wheeltrack and non-wheeltrack samples, and these will also exhibit some differences in microtexture.

The outlying points in the region of 0.8 to 1.4 mm texture depth in Figure 6.7 are open graded asphalt samples. These outliers are thought to be anomalous and may reflect that the water used to wet these samples drained away before frost formation. Nevertheless it cannot be discounted that this is a genuine effect which could be further investigated.

These outliers aside, Figure 6.7 shows that frost conditions reduce skid resistance to only 40-60% of the wet skid resistance for textures less than 1 mm, and to 50-70% of the wet skid resistance for textures about 2-3 mm in depth.

Figure 6.6 shows that ice conditions give a much greater reduction in skid resistance to only 20-40% of the wet value for textures less than 1 mm and 40-55% for textures about 2-3 mm in depth.

7.   Discussion

7.1   Limitations of BPT Measurements

The preceding analysis showed that, in natural frost and ice conditions, the extent that macrotexture could limit the effects of frost or ice is small. The findings of this study need to be tempered by concerns as to the realism of the simulated condition and of the extent that the BPT can represent the skidding of a vehicle on ice or frost.

Before carrying out this experimental work the effect of macrotexture had been expected to be more like that shown by Figures 6.3 and 6.4 for light frost and medium frost respectively, in the laboratory test rooms. That is, ice and frost effects would be small above a definite threshold texture depth. However the frost rooms do not allow for the radiative heat loss effects that occur on roads, and therefore do not adequately show how a natural frost forms on a road. Tests conducted using natural frost show the effect of frost on skid resistance is similar to that of ice. However, the field observations of frost formation are consistent with laboratory tests and the small effect of macrotexture. The effect of radiative cooling of the road surface is that the tips of the chipseal to cool first, so they are the locations where frost or ice form first. In use the BPT is adjusted so that it generally contacts only the upper portion of the chip. Because these are the first parts to be frosted, its readings will be immediately affected by any ice or frost present.

Generally the BPT is accepted as giving a reasonable representation of the skid resistance of a vehicle for speeds less than 50 kph. However the extent that the BPT accurately represents the effect of ice or frost on skid resistance for vehicles depends on the detail of the effect of the car type trafficking the frost- or ice-covered surface. For example, if there is much greater weight on the car tyre, it is squeezed further around the road microtexture, giving more grip.

As Figure 7.1 shows, the main contact area of vehicle tyres on chipseals tends to be confined to the upper portion of the chip only, although the contact pressure is accentuated by the load carried on a smaller contact area. Even with only a thin film of ice, the skid resistance can be expected to be low for vehicles as the ice will be tightly adhered to the road surface. Moore (1975) notes that near the freezing point, ice films can have very low skid resistance especially as the tyre pressure accentuates the problem by melting a thin film of water between the tyre and the ice layer. This water film destroys most of the potential friction.

7.2   Clearing of Frost by Traffic

The field observations showed that, with light to medium frost conditions, the frost crystals were only lightly adhered to the road surface and were partially cleared by trafficking. Fully assessing the influence that this clearing effect could have on the skid resistance was not possible in the context of this mainly laboratory-based study.

Figure 7.1   **Comparison of the contact made by the tyre footprint with the chips in two grades of chipseal (coarse and fine), and the point pressures (N/m) generated at the high points of the chips.**
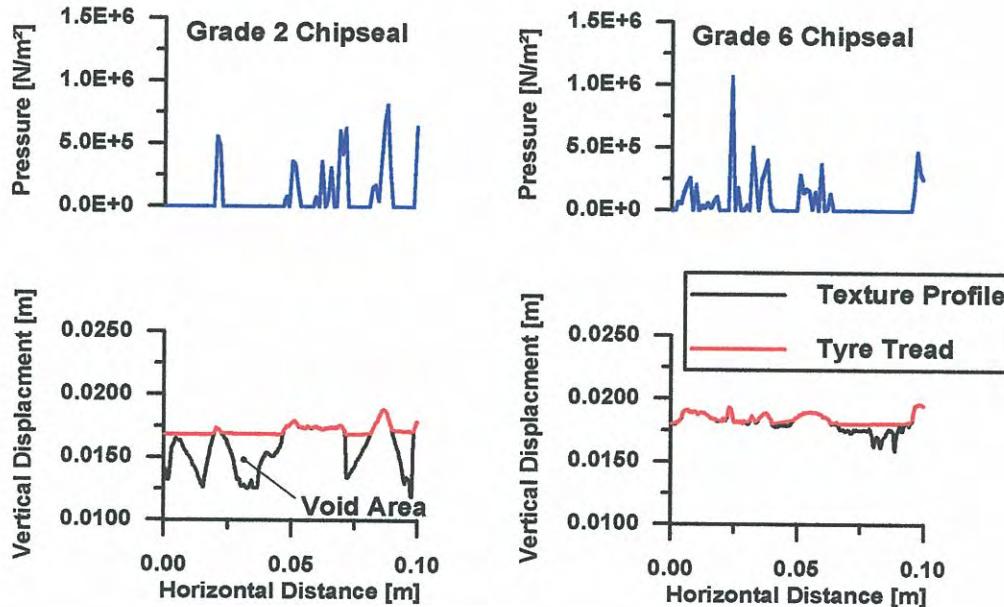
However the measurements in frost conditions described in Section 4.3 of this report give some insight. With asphaltic concrete, little increase in skid resistance occurs after trafficking, but the partially trafficked chipseal had a skid resistance close to the skid resistance of the chipseal that has been wetted by water. The macrotexture possibly may have a stronger effect in frost than was revealed by this study, but this effect would need to be established by a further study, probably field-based. The study would have to use a test vehicle, or weighted tyre testers, rather than the BPT so that effects of rotating weighted tyres can be determined.

No opportunity arose in the study to observe the roads under ice conditions. However the ice is much more tightly adhered to the road surface than frost, any clearing effect from the tyre will be minimal in light traffic. Thus the BPT probably adequately represents skid conditions for thin ice on the road.

7.3   Implications for Road Management

The plan had been to produce advice, by way of guidelines, on selecting road surfaces that will better manage the effects of frost and light ice. However, given the uncertainties in measuring skid resistance at low temperatures, the limitations of the test rooms in forming the frost condition, and concerns that greater texture effects may be shown by tyres on coarse macrotextures, then further research is needed to develop such guidance.

The evidence from this current study is:

- Fine texture surfaces, i.e. those about 0.8 mm or less, appear to be very vulnerable to the effects of frost and ice.

- Coarse texture surfaces (those about 2-3 mm) are less vulnerable to the effects of frost and ice, but the improvement compared to that obtained from fine textures, is not large.

Although a concern is that the BPT may not show the full extent of the macrotexture in frost conditions, the BPT probably adequately shows the effect of the ice condition. As shown in Section 2 of this report, conditions could probably favour the formation of thin ice as readily as white frost. In ice conditions the effect of macrotexture is also small.

The effect of frost or light ice is significant in road management terms as it negates much of the current skid resistance strategy for wet roads, which is to provide increased skid resistance for areas of increased risk.

In frost and ice conditions, skid resistance is greatly reduced compared to the wet condition. Likewise, the differences in skid resistance for the range of surface types are much less than in the wet condition.

7.3.1 Minimum Texture Depth

The trends identified by this study indicate that road surfaces in locations where frost or ice occur intermittently, and the extent of those conditions is not severe, should be maintained at a substantial macrotexture. A lower limit of about 1.5 mm texture depth, measured as MPD, is suggested.

Texture however cannot be relied on as the only means of improving skid resistance where frost and light ice occur.

7.3.2 Effects of CMA

Work undertaken in a related project examined the effect of the de-icing salt CMA, and the results are is illustrated in Figure 7.2.

Figure 7.2 shows that the skid resistance of the surface wetted with water plus CMA is much less than that of the surface wetted with water only. However the skid resistance of the surface wetted with water + CMA is considerably greater than that of the ice-covered surface.

This then points to an additional strategy for managing the hazard, which is to apply CMA as a prevention treatment to those highway sections where frost and ice can be forecasted.
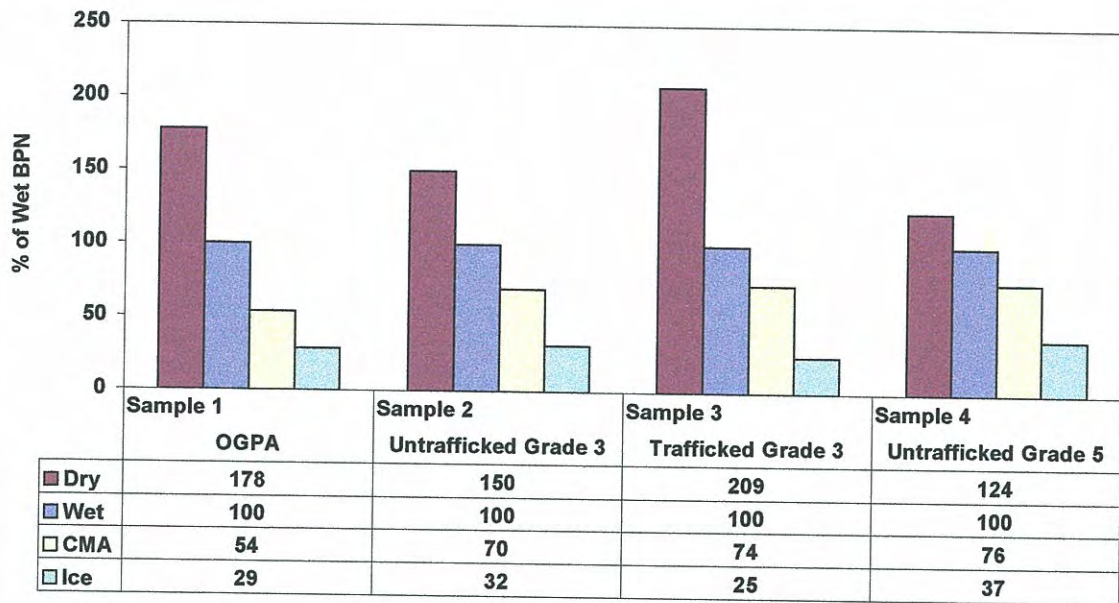
	Sample 1 OGPA	Sample 2 Untrafficked Grade 3	Sample 3 Trafficked Grade 3	Sample 4 Untrafficked Grade 5
■ Dry	178	150	209	124
■ Wet	100	100	100	100
□ CMA	54	70	74	76
□ Ice	29	32	25	37

Figure 7.2   Comparison of skid resistance on surfaces that are dry, wet without CMA, wet with CMA, and with ice (without CMA).

7.3.3   Identifying Locations of Frost Formation

The remaining issue is how to identify the areas where frost and ice formation are likely, given that most of these are scattered short stretches of road for which Road Weather Information Systems (RWIS) would not be affordable. RWIS are sophisticated warning systems that link road conditions such as pavement temperature, weather conditions and weather forecasts to predict the formation of frost and ice.

Section 4.2 noted that on those road types which were the focus of this study, i.e. roads where frost and ice occur only on short sections and form only occasionally in the year, frost occurred on road sections which were exposed to either very short or no exposure to direct sunlight. Therefore by identifying and treating these areas, skid hazard in the frost could be countered.

The most rigorous way would be to locate these by thermal mapping. But an effective (and cheaper) option to identify most road sections having these conditions is careful visual inspection and manual recording in winter, when the sun is low in the sky. This inspection could also be made in other months but allowing for the angle of the winter sun in the observations.

8.   Conclusions

- Frost first forms on chipseal on the tips of the chips, then spreads over the chips and bitumen layer as the frost intensifies. In general this frost is only loosely adhered to the chips.

- Because frost forms this way, the effect of macrotexture in maintaining skid resistance in these conditions appears to be small from this study. The effect of macrotexture under weighted rotating tyres may be greater.

- Macrotexture shows only a small effect in maintaining skid resistance when thin ice layers are present. This ice is tightly adhered to the chip, and therefore it is expected to represent the on-road situation.

- Smooth surfaces appear to be very vulnerable to the effects of frost and ice, i.e. have low skid resistance, because the ice covers the entire surface, and it cannot be easily displaced into the voids between the chips.

- The loss of skid resistance is great, being 30% to 60% of the wet skid resistance value. This loss is significant for road management as it makes policies providing higher skid-resistant surfaces for higher risk road sections difficult to achieve for frost or ice conditions.

- The influence of microtexture is unclear. With some road surface types those samples that had higher skid resistance in the wet condition (which indicates a more harsh microtexture) also had higher skid resistance in the frost or ice conditions. However the pattern is inconsistent.

- The study shows a small improvement in ability to retain skid resistance for surfaces that have a macrotexture greater than 1.5 mm (measured as MPD).

- In this study, locations where frost or ice can be expected appear to be stretches that are shaded from the sun for all or most of the day. These locations are readily (and cheaply) identified by visual inspection, but thermal mapping would be a more rigorous method.

- Using the British Pendulum Tester at less than 5°C raises uncertainties. Although this study has identified them, it has not resolved them. These uncertainties relate to the effect of the recorded friction on a surface increasing as the temperature decreases. The relationship between friction measurement and temperature below 5°C was found to be inconsistent.

- The controlled climate rooms used in this research to examine the effect of frost on roads do not provide conditions comparable to natural conditions. However, they are adequate for examining the effects of ice on road surfaces, and the effects of low temperature on methods of measurement.

9.   Recommendations

- A lower limit of about 1.5 mm macrotexture is suggested. However, because the effectiveness of macrotexture on skid resistance is not reliable, additional strategies are suggested for managing frost and light ice conditions in mild or moderate New Zealand winter conditions. An example is the use of CMA.

- If the BPT is to be used at low temperatures (e.g. below 5°C) for measuring skid resistance, then additional research is needed to reliably identify the friction–temperature relationship.

- Future studies of the relationship of skid resistance and road texture under frost and ice conditions should use measurement procedures that are more responsive to macrotexture. Examples are the use of the Grip Tester or of instrumented vehicles which have weighted tyres.

10. References

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Appendix

Temperature Corrections for British Pendulum Tester

Temperature Corrections for BPN Measurements

A1. Quadratic v Linear Correction

As shown in Figure 5.2, the Road Note 27 temperature correction is quadratic:

$$BPNC = -0.005T^2 + 0.45T - 7 \tag{2}$$

The data from the current study (Section 5.2) indicates that a linear equation (1) is the best choice, as the quadratic coefficient (3) is almost zero:

Linear: $BPNC = 0.4193T - 8.2515$, $R^2 = 0.9178$ (1)

Quadratic: $BPNC = -0.0004T^2 + 0.4321T - 8.3319$, $R^2 = 0.9178$ (3)

Both the linear (1) and quadratic (3) equations give the same R^2 value.
(*BPNC – British Pendulum Number Correction)

A2. Effect of BPT Machine

Figure A1 indicates that whichever machine is used (e.g. Central Labs, ex-Wanganui, or ex-Timaru), it has no effect on the BPN. This is also apparent from Figure A2.
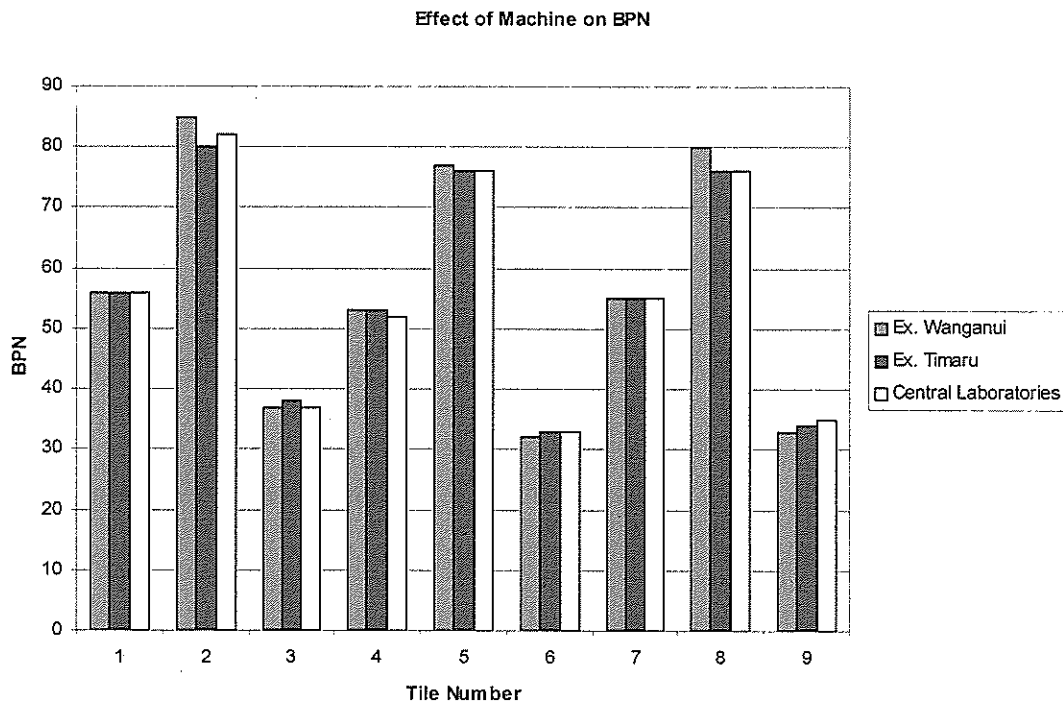

Effect of Machine on BPN

Figure A1   Effect of BPT machine on BPN.

A3. Effect of Relative Humidity

Regressions were carried out using (1) room temperature only, and (2) both room temperature and relative humidity. Results indicate that humidity does not have a significant effect on BPN Correction (Table A1).

Table A1. Multivariable regression results for effect of relative humidity on Tile 2.

Regression Output	Room Temperature Only	Room Temperature & Relative Humidity (%)
R Square	0.913	0.914
Intercept P-value	1.145e–10	6.234e–6
Room Temperature P-value	1.847e–10	6.218e–10
Relative Humidity P-value	n/a	0.696

A4. Effect of Time Delay

Figures A2-A4 indicate no difference between allowing 10 minutes for the machine to reach test chamber temperature, and having the machine permanently in the room while the temperature was changed. A 30 minute stabilisation period was allowed at the specified room temperature.

A5. Effect of Tile Texture

Figures A2-A4 show variability for each tile type for:

1. The threshold temperature above which the relationship between friction measured and temperature is stable.

2. The correction that should be applied when the friction was measured to allow for the low temperature conditions at that time.

A6. Effect of Temperature

Of the temperatures measured, room temperature is the best predictor of BPN correction. This is summarised in Table A2 below for tile 2. It is evident that all 5 temperatures are highly correlated, and it is therefore not possible to distinguish the effects of each temperature separately.

Table A2. Correlations of temperatures for Tile 2.

	Relative Humidity (%)	Room Temperature (deg. C)	Slider Temperature (deg. C)	Water Temperature (deg. C)	Wet Tile Temperature (deg. C)	Dry Tile Temperature (deg. C)	BPN Correction
%RH	1						
Room Temperature	−0.109	1					
Slider Temperature	−0.026	0.993	1				
Water Temperature	−0.062	0.964	0.972	1			
Wet Tile Temperature	−0.010	0.988	0.998	0.974	1		
Dry Tile Temperature	−0.011	0.989	0.998	0.974	0.999	1	
BPN Correction	**−0.160**	**0.971**	**0.964**	**0.929**	**0.962**	**0.961**	**1**

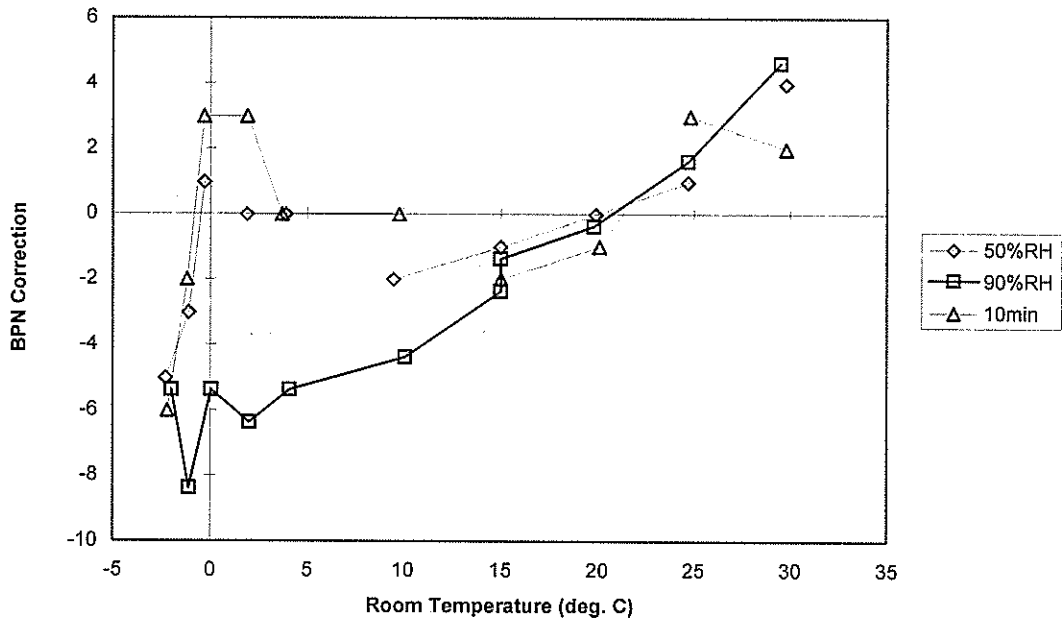Tile 1: BPN Correction vs Room Temperature

Figure A2. Room temperature correction for BPN on Tile 1.

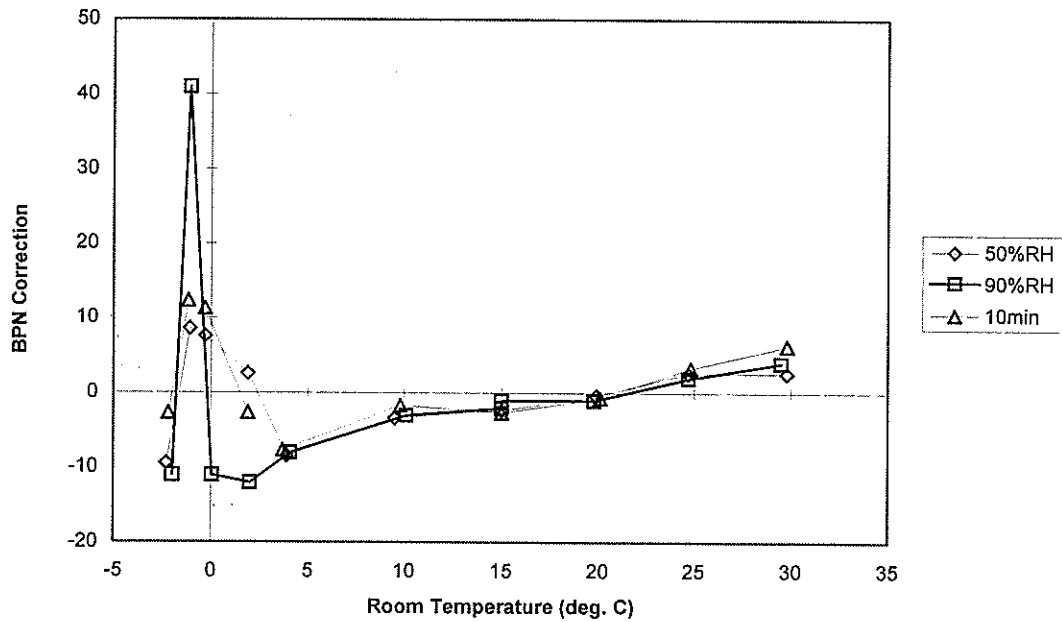Tile 2: BPN Correction vs Room Temperature

Figure A3. Room temperature correction for BPN on Tile 2.

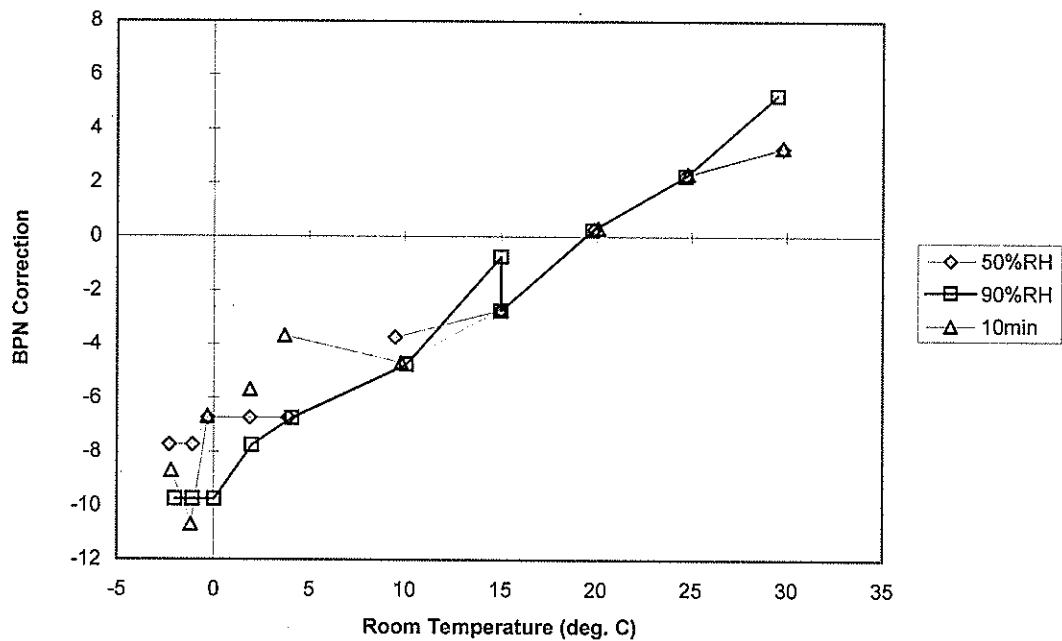Tile 3: BPN Correction vs Room Temperature

Figure A4. Room temperature correction for BPN on Tile 3.

A7.   Effect of CMA Coating

On the basis of Figure A5, no substantial differences to the corrections are required when using CMA coatings.
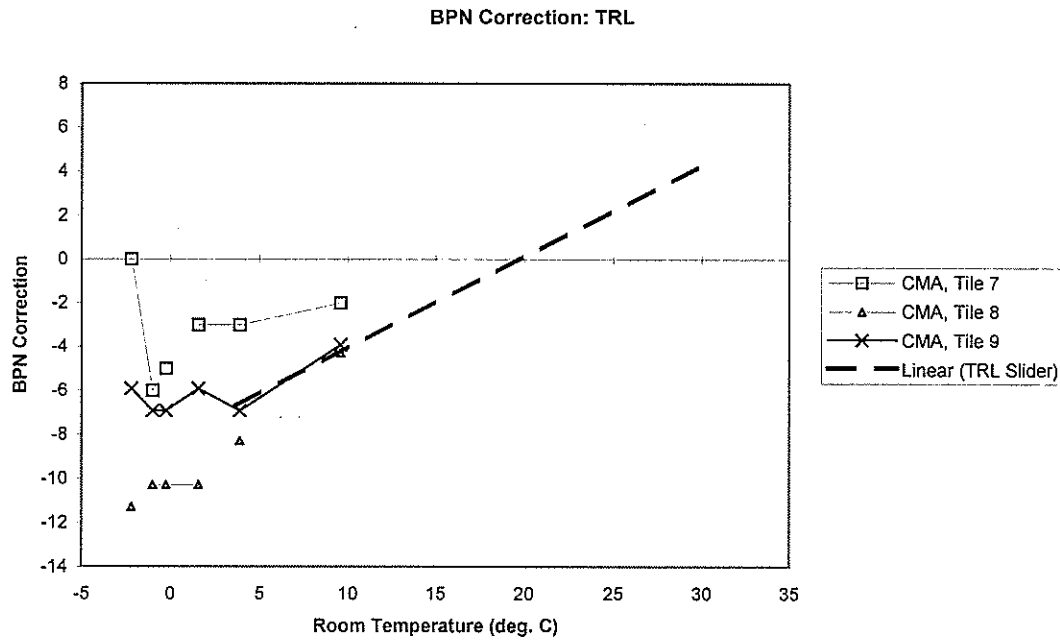
BPN Correction: TRL

Figure A5   Room temperature correction required for CMA-coated tiles.