TEMPERATURE INFLUENCE ON SKID RESISTANCE MEASUREMENT

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ABSTRACT

This paper presents the findings of an investigation, carried out in Queensland, to determine the temperature influence on the skid resistance F60 measurements, the appropriate reference temperature for Queensland conditions and an F60 – surface temperature correction procedure.

Although the field investigation was restricted to asphalt surfaces, the paper also discusses the air temperature – surface temperature relationship, skid resistance – temperature correction factors used in Australia and temperature regimes in Australia particularly in asphalt, spray seal and concrete surfaces.

The paper concludes that most skid resistance temperature criteria, used in Australia, are based on UK temperature conditions which, although appropriate for Melbourne and Canberra conditions, are totally unsuited for Queensland and most of northern Australia.

INTRODUCTION

Temperature is known to have a significant influence in skid resistance measurement of wetted surfaces with skid resistance reducing with increasing temperature. Most skid resistance test methods allow correction of the measured skid resistance value, for the temperature on the day, to what would have been measured under reference temperature conditions. However, these methods use different temperature measurements and correct the skid resistance values to various reference temperatures.

The Queensland Department of Transport and Main Roads operate Norsemeter and ViaFriction skid testers that can operate in variable or fixed slip modes. These skid testers are generically similar and both use the ASTM Standard E-1551 Test Tyre (ASTM (2008)). The difference between the two devices is that the Norsemeter uses hydraulics to control the braking action while the ViaFriction uses electrical force. Both units have been calibrated, by their manufacturer, against OSCAR, a reference device used in the PIARC International Trial (PIARC (1995)).

This paper presents the results of an investigation to determine, for asphalt surfaces only,

- the temperature influence on the skid resistance F60 measurements produced by the Queensland Department of Transport and Main Roads variable slip (Norsemeter) and controlled slip (ViaFriction) skid testers,
- the appropriate reference temperature for Queensland conditions and
- suitable F60 temperature correction factors.

TEMPERATURE EFFECTS

The temperature at the pavement tyre interface (that is, air, tyre, water and pavement surface temperature) has been identified as having an affect on pavement friction measurements. Increases in temperature result in a reduction of friction. This reduction is not as marked at high slip speeds (Lou (2003)).

Tyre temperature is considered to be affected by load, tyre pressure and vehicle speed as well as air, water and pavement surface temperature. In skid resistance testing, the load, tyre pressure and vehicle speed are constant leaving only air, water and pavement surface temperatures as variable influences. Oliver (1989) showed that tyre temperature was related to pavement and air temperature.

$$t = 12.3 + 0.48(Ta + Tb)$$

where t = tyre temperature (oC)

Ta = air temperature (oC) and

Tb = pavement (surface) temperature (oC).

Little has been published about the effect of water temperature on skid resistance measurement. Lou (2003) found that water sprayed during skid testing had no significant cooling effect on the pavement temperature. This is understandable as the water film is generally only 0.5 to 1.0 mm thick and sprayed to a width of 100 to 200 mm. In the case of the Queensland skid testers, their 0.5 mm thick, 100 mm wide water film can be assumed to immediately heat up to the pavement surface temperature and initial water temperature would have negligible influence on the skid resistance measurement.

Hence, if a relationship exists between air and pavement surface temperature, then either of these temperatures can predict tyre temperature and be used skid resistance correction.

AIR – PAVEMENT TEMPERATURE RELATIONSHIP

A bituminous pavement surface is a medium that absorbs heat by contact with the air and from direct radiation from the sun. During the day, the surface becomes much hotter than the ambient air temperature. At night, the surface looses heat until, with thin surfacings, the surface temperature approaches or equals the ambient air temperature. Thick asphalt surface layers can absorb so much heat during the day that even on the coldest of Australian nights, the surface temperature is still above the air temperature as this typical Canberra data (250 mm slab), from Dickinson (1981) shows.

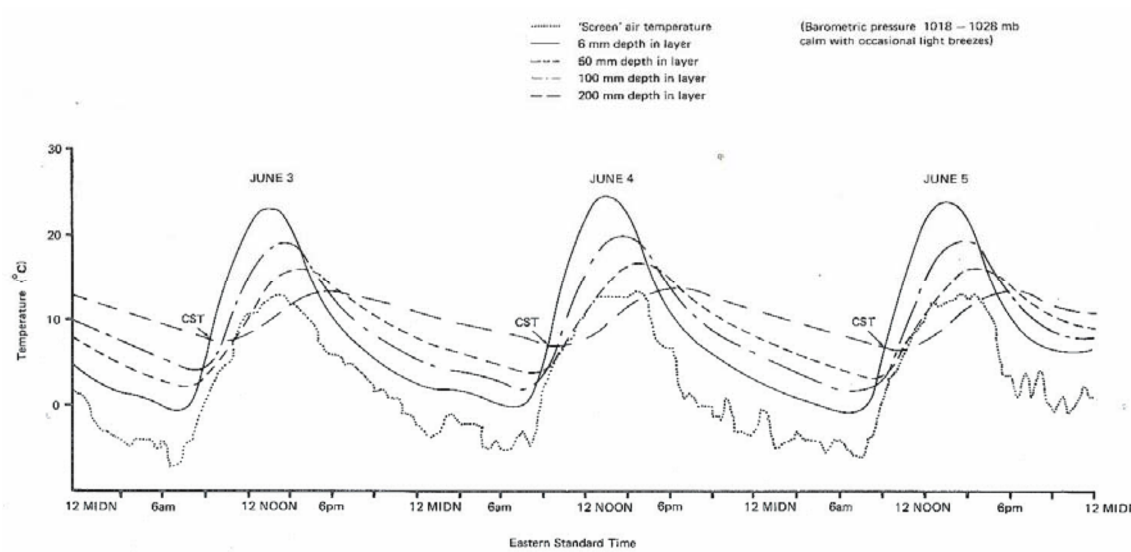


Figure 1: Temperature Conditions - Typical Cold Season Days - Canberra

Oliver (1980) presented the following two relationships for temperature correction of skid resistance values :-

$$SRV20 = SRVt / (1-0.00525(t-20))$$

Where t = surface temperature in oC and

$$SRV20 = SRVt / (1-0.00816(t-20))$$

Where t = air temperature in oC

From these equations, the following relationship between air temperature and surface temperature can be extracted :-

$$Tp = 1.554(Ta) - 11.09$$

Where Tp = pavement surface temperature in oC and

Ta = air temperature in oC.

This relationship indicates that at 20 oC the surface temperature is equal to the air temperature. Figure 1 indicates that with a 250 mm asphalt layer, the stored heat from daytime radiation, prevents this from occurring even on the coldest of nights.

DTMR (1985) monitored the temperature conditions, during daylight hours, in both a 50 mm and a 125 mm asphalt slabs at Nundah from 13 October 1982 until 4 January 1985. The temperature readings were recorded manually at four random times per day, Monday to Friday, between 8 am and 4:30 pm. The following locality map presents the layout of the slabs which are numbered 3 and 4 respectively.

Figure 2: Nundah Test Slabs

The results of air temperature and surface temperature (10 mm depth) for the 50 mm asphalt slab are presented in figure 3 together with the extracted (Oliver (1980)) air temperature – pavement temperature relationship.

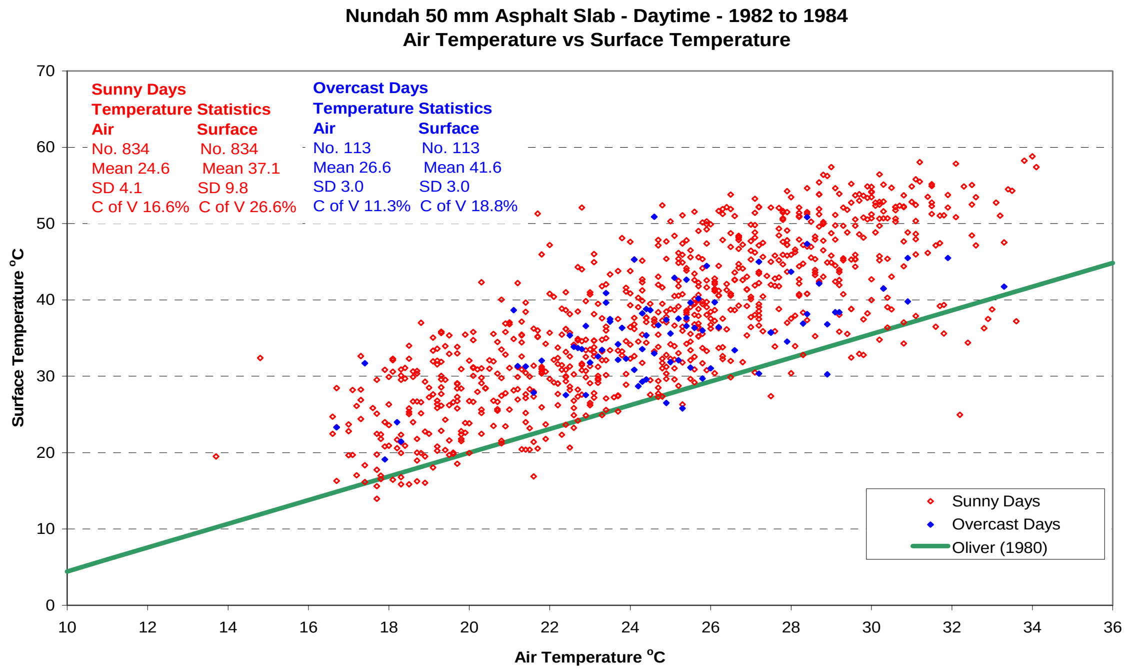


Figure 3: Daytime Air vs Surface Temperature Relationship – Brisbane

These results are all well above the extracted Oliver (1980) relationship. The latter is obviously based on much colder climatic conditions than those that exist in Brisbane, even possibly from the UK. Queensland, unlike the southern states, has it's rainfall in the summer months, hence, overcast days generally occur in summer. The above temperature statistics reflect this. The results also indicate that sunny days, in Brisbane, made up 88% of the population. By comparison, in the southern region of the UK only 34% of the days are sunny (UK Met Office Stats 1971 to 2000).

Figures 4 and 5 present typical sunny day temperature data, by time of day, for the 50 mm and 125 mm depth slabs in the month of January.

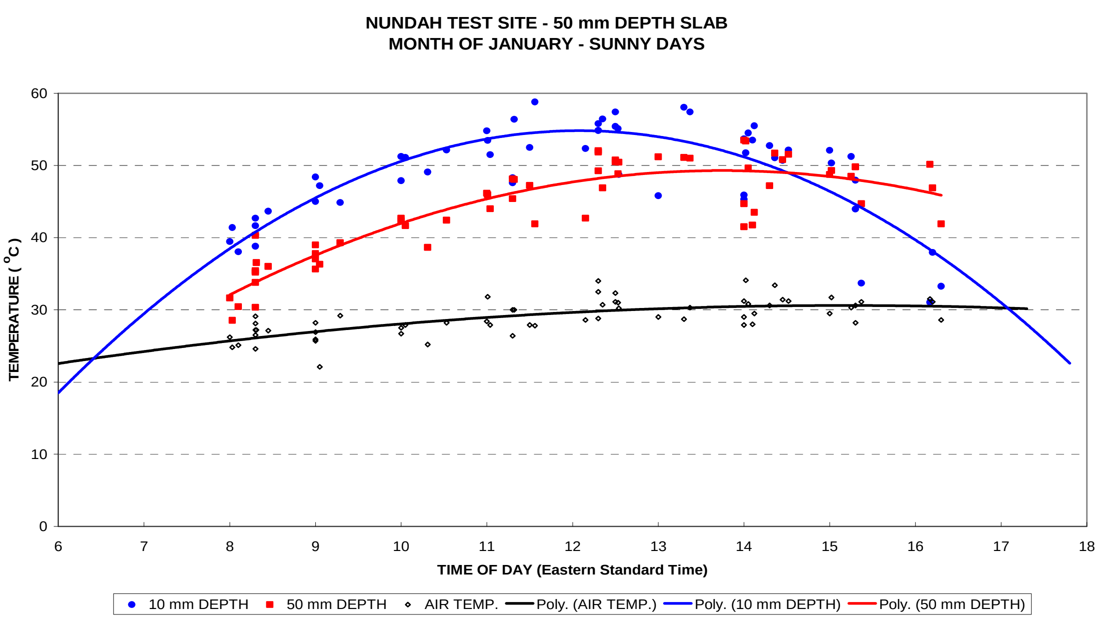


Figure 4: Daytime Temperature Conditions – Sunny Summer Days -50 mm Slab

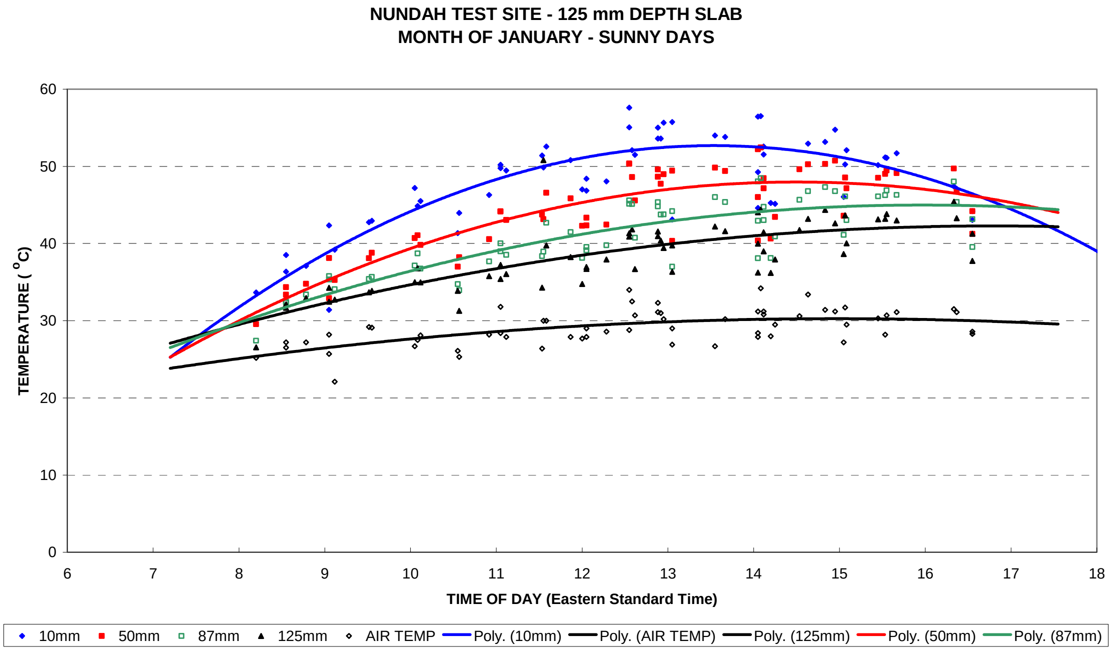


Figure 5: Temperature Conditions – Sunny Summer Days -125 mm Slab

This data shows that, unlike the Dickinson (1981) findings for 250 mm asphalt slabs, on thinner slabs the air and surface temperatures appear to be equal at dawn and most likely are equal again some time after sunset with the surface temperature drop in the 125 mm slab lagging that in the 50 mm slab.

It is therefore considered that there is no unique relationship between surface temperature and air temperature for asphalt surfacings as the relationship is influenced by asphalt thickness and climatic conditions particularly number of daylight hours and cloud cover. It would appear that surface temperature, which is generally much greater than air temperature, would be the best measure to use for assessing temperature effects on skid resistance.

TYPICAL TEMPERATURE CORRECTION FACTORS

Portable or British Pendulum Tester

TRRL (1969) presented the following figure for temperature correction of skid resistance factors to a reference surface temperature of 20oC.

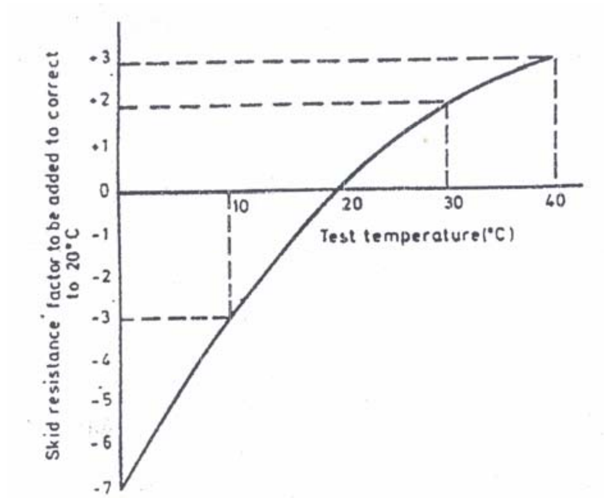


Figure 6: TRRL Temperature Correction

This relationship, which is only valid for temperatures below 40 oC, can be represented by the following equation :-

SRV20 = SRVt + (-5x10-5(t)2 + 0.003(t) + 0.4017)

Where SRV20 = skid resistance value at 20oC,

SRVt = skid resistance value at toC and

t = surface temperature in oC.

The Oliver (1980) developed relationship for temperature correction using surface temperature, as presented below, is used by Western Australia (MR WA (1996)).

SRV20 = SRVt / (1-0.00525(t-20))

Queensland (DTMR (1982)) has also adopted this relationship but with the reference temperature raised to 30 oC.

SRV30 = SRVt / (1-0.00525(t-30))

AS (1999) use the following relationship for temperature correction as does New South Wales (RTA (2001)). Note:- These methods are primarily for laboratory testing of prepared samples to determine Polished Aggregate Friction Value. The temperature correction is contained in Appendix A – Testing of Materials other than Aggregates and for Materials in the Field.

SMVC = SMVT ((T + 100)/123)

Where SMVC = Skid Mean Value corrected for Temperature,

SMVT = Skid Mean Value at Temperature of Test and

T = recorded Air Temperature at Test in oC.

From this formula, it can be seen that the reference temperature is 23 oC (ambient air).

SCRIM

The UK generally specify a Mean Summer SCRIM Coefficient Method (HD 28/04) designed to provide skid resistance readings under the worse climatic conditions. Although out of season SCRIM surveys can be performed, the policy provides no guidance on temperature correction.

Kennedy et al (1990) suggests that "increasing temperature reduces SFC readings by 0.003 per oC".

RTA/VicRoads (1995) have adopted a similar relationship, combined with a 20 oC reference surface temperature, for temperature correction as presented below:-

SR20 = SR + 0.3(T – 20)

Where SR = SCRIM Reading (SFC x 100),

SR20 = SCRIM Reading corrected to 20 oC and

T = surface temperature in oC.

US Breaking Trailer

Definitive information on reduction in skid resistance with temperature increase is limited. The following relationship was developed, for various bituminous surface types, from trials carried out in Indiana (Elkin et al (1980)) using locked wheel skid testers operating at 40 mph (64 km/h) as reported by Lou (2003).

SNC = 5.09 – 0.232(Tp)

Where SNC = skid number correction and

Tp = pavement temperature in oC.

Lou (2003) developed a skid resistance, temperature, slip speed model for asphalt surface mixes used in the Virginia trials which is presented below.

SNS(T) = (159 – 1.14(T))*e-((2.27-0.02(T))/100)*V

Where SNS(T) = skid number using a smooth tyre at temperature T,

T = pavement temperature (oC). and

V = testing speed (km/h).

The Lou (2003) model shows a reduction in the correction factor with rise in surface temperature and increase in test (slip) speed.

Summary

With the exception of ASTM (1999), all methods use surface or pavement temperature for temperature correction of skid resistance results. The procedures that originated in the UK use a reference temperature of 20 oC. What is a suitable reference temperature for Queensland in particular and Australia in general?

TEMPERATURE REGIMES IN AUSTRALIA

Asphalt

Dickinson (1981) reported on the temperature regimes in asphalt and spray seal sites in Melbourne, Sydney, Brisbane, Perth, Canberra and Darwin. Each site was continuously monitored for at least one year. A similar study had been reported for a site in Townsville by Dickinson (1977).

Yearly surface temperature distributions, in a 40 to 50 mm asphalt slab, are presented in figures 7 and 8. These results are in 6 oC temperature lots. The shaded area represents the median temperature band for Canberra.

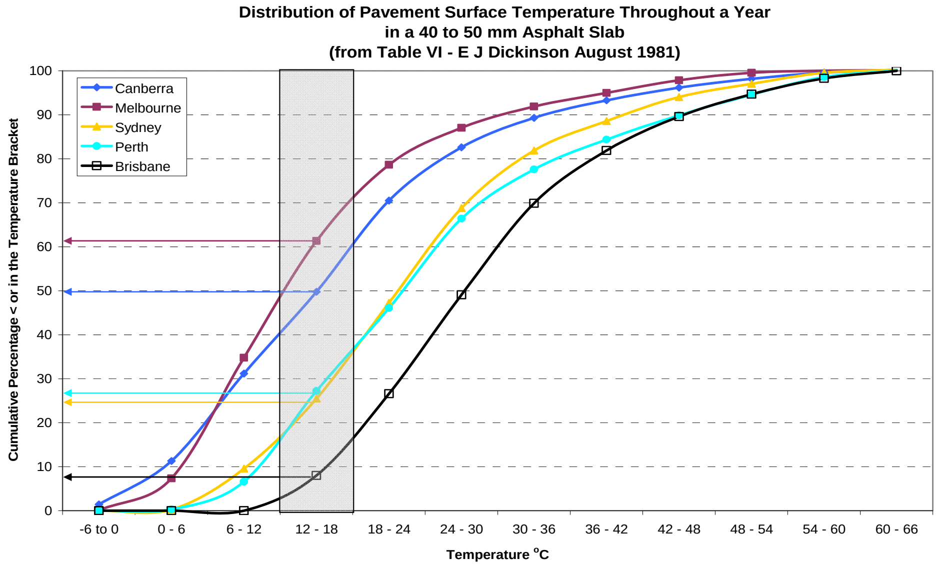


Figure 7: Cumulative Surface Temperature Distributions (% less than)

This data shows that in Melbourne and Canberra, the surface temperature is at or below 18 oC for 50% or more of the time. In Brisbane, these low temperatures are only experienced for 8% of the year. While a reference surface temperature of 20 oC would be appropriate for Melbourne and Canberra, it is totally unsuited for Brisbane.

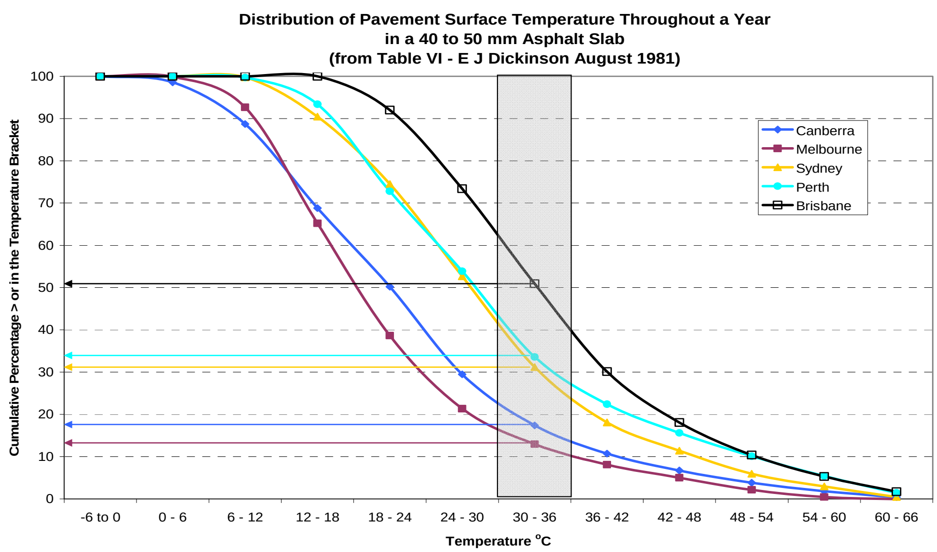


Figure 8: Cumulative Surface Temperature Distributions (% greater than)

This distribution indicates that for 51% of the year, surface temperatures in Brisbane above 30 oC. This supports the adoption of 30 oC as the reference temperature for Brisbane and possibly Queensland. The shaded area represents the median temperature band for Brisbane.

Figure 9 presents the percentage of year spent above 30 oC at a 50 mm depth in thick (200 to 250 mm) asphalt layers.

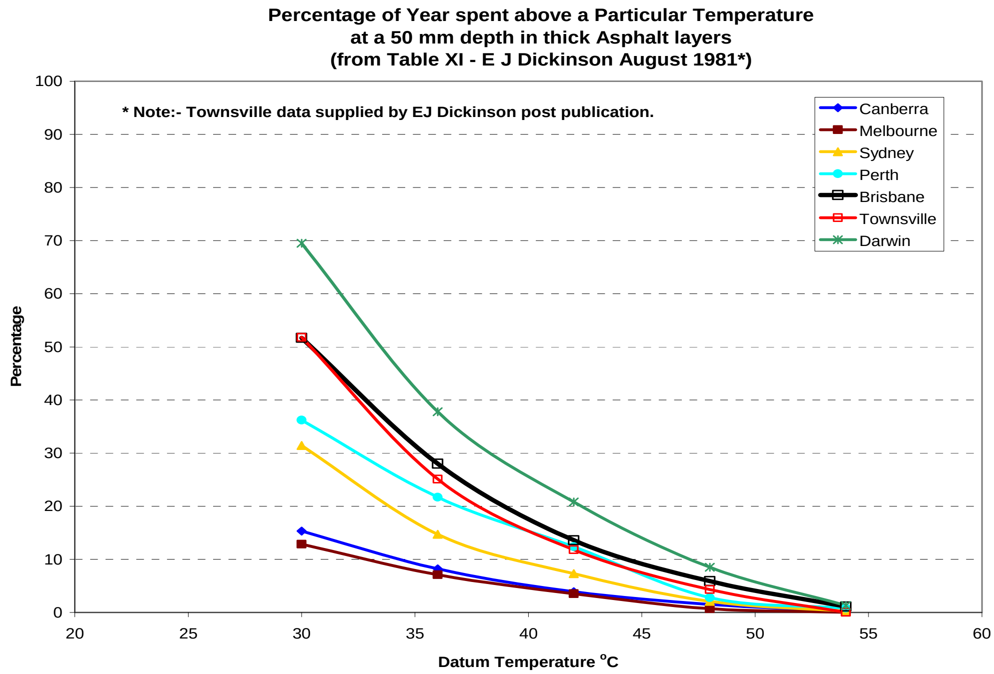


Figure 9: Temperature Distributions – Comparison with Darwin and Townsville

This data shows that asphalt temperature conditions in Townsville and Brisbane are similar even though separated in latitude by 7.5o (835 km). This similarity is attributed to Townsville's shorter daylight hours and increased cloud cover compensating for the higher daily air temperatures and hence supplying the same heat to the asphalt as occurs in Brisbane. In Darwin for 70% of the time the asphalt is above 30 oC. Therefore, although a 30 oC reference surface temperature is appropriate for Brisbane and Townsville, it may need to be raised to say 35 oC for north west Queensland which may have similar climatic conditions to Darwin.

In figure 10, obtained from Australian Government Bureau of Meteorology, the annual average daily solar exposure is presented in megajoules per square metre. This measure of heat energy generally reflects the ranking of capital city average annual asphalt temperatures observed by Dickinson (1981). It also shows that in Queensland, the area west of the Charleville, Alpha, Hughenden, Georgetown and Weipa (the 21 megajoules per square metre boundary) may share asphalt temperature conditions that are more reflective of Darwin conditions than those that exist in the rest of Queensland (as reflected by the Brisbane Townsville data).

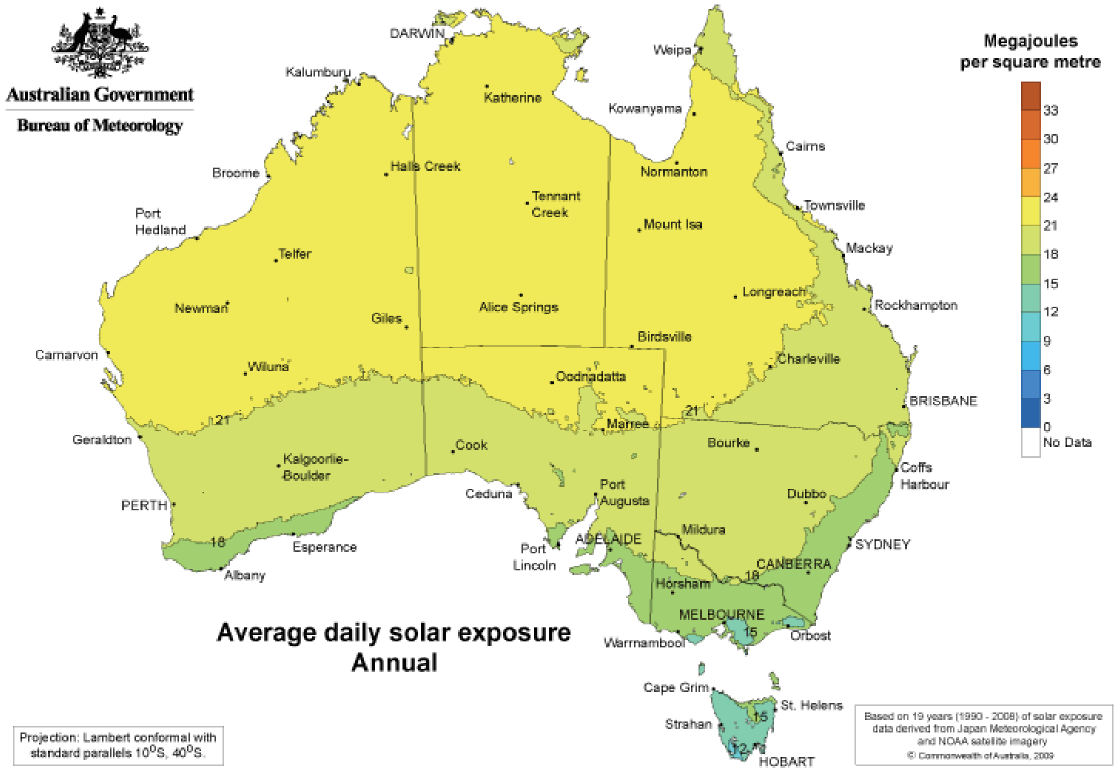


Figure 10: Annual Average Daily Solar Exposure

In summary, the reference asphalt surface temperature of 20 oC, as used in most of Australia, is only appropriate for areas with climatic conditions similar to Melbourne and Canberra. In Queensland, the adopted 30 oC reference temperature is appropriate for the eastern coastal strip and the south east corner but may be too low to be representative of the rest of the State.

Spray Seals

In the Dickinson (1981) study, two of the sites (Sydney and Perth) included standard spray seal sites. The surface temperature distributions of the spray seal sites with the adjacent 50 mm asphalt sites are compared in figures 11 and 12.

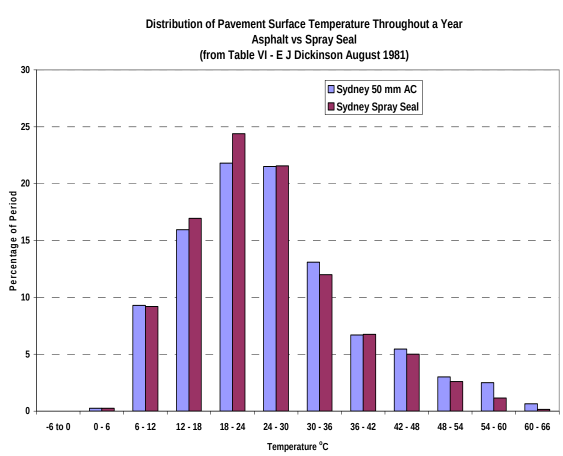


Figure 11: Asphalt vs Spray Seal (Sydney)

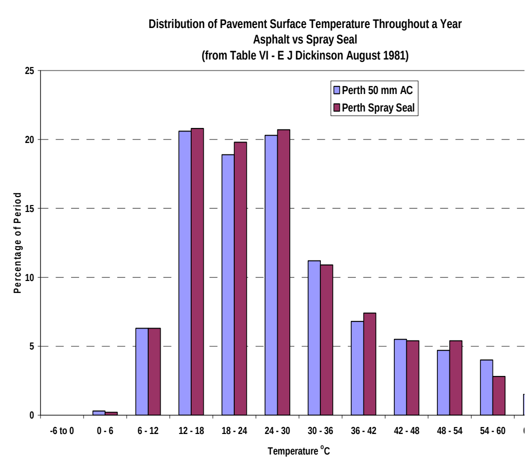


Figure 12: Asphalt vs Spray Seal (Perth)

These results show that there is only a small difference in surface temperatures between asphalt surfaces and spray seal surfaces. At the Darwin site, two different colour aggregate seals were also monitored (Dickinson (1981)). These results are presented in figure 13. The asphalt site at Darwin was 250 mm thick. To determine the relationship between surface temperatures on thin and thick asphalt layers, the data from the Nundah site (DTMR (1985)) was used to provide an indication. These results are presented in figure 14.

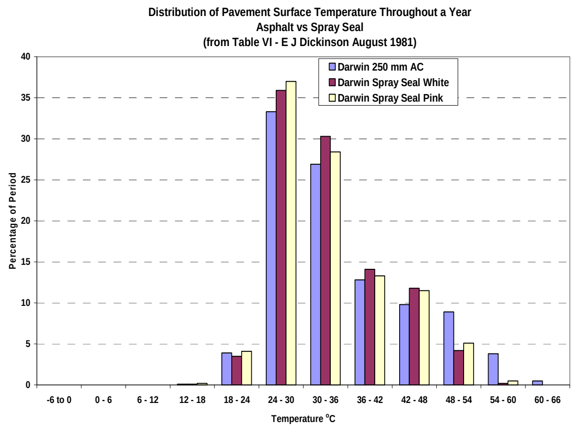


Figure 13: Asphalt vs Spray Seal (Darwin)

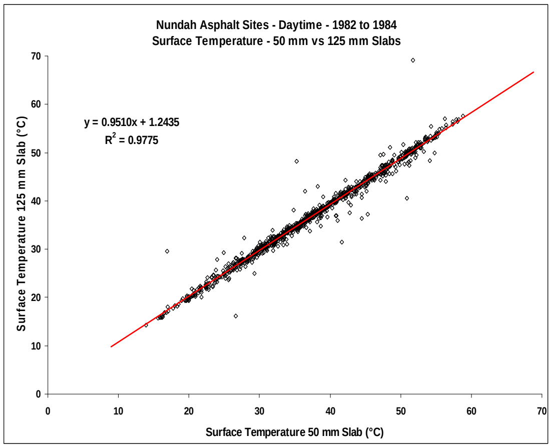


Figure 14: Surface Temperature (Brisbane)

The Nundah results indicate that the surface temperature in thick slabs is slightly lower than in adjacent thin slabs. It can therefore be concluded that had Darwin had a 50 mm asphalt slab for comparison with the light coloured spray seals, the asphalt and seal temperatures would be even closer. This would then support the findings from Sydney and Perth that there is little difference between spray seal and thin asphalt surface temperatures.

Concrete Surfaces

During February 2010, surface temperatures were monitored on a 200 mm concrete slab and an adjacent 50 mm asphalt slab at the Nundah Test Site in Brisbane (DTMR (2010)). These probes were set at a depth of 10 mm below the surface. The air temperature was also recorded in a shaded area approximately 200 mm above the junction of the concrete and asphalt slabs (refer locality map on page 3 – slabs numbered 1 and 2 respectively). These temperatures, together with air temperatures from the nearby Brisbane Airport site are presented in figure 15.

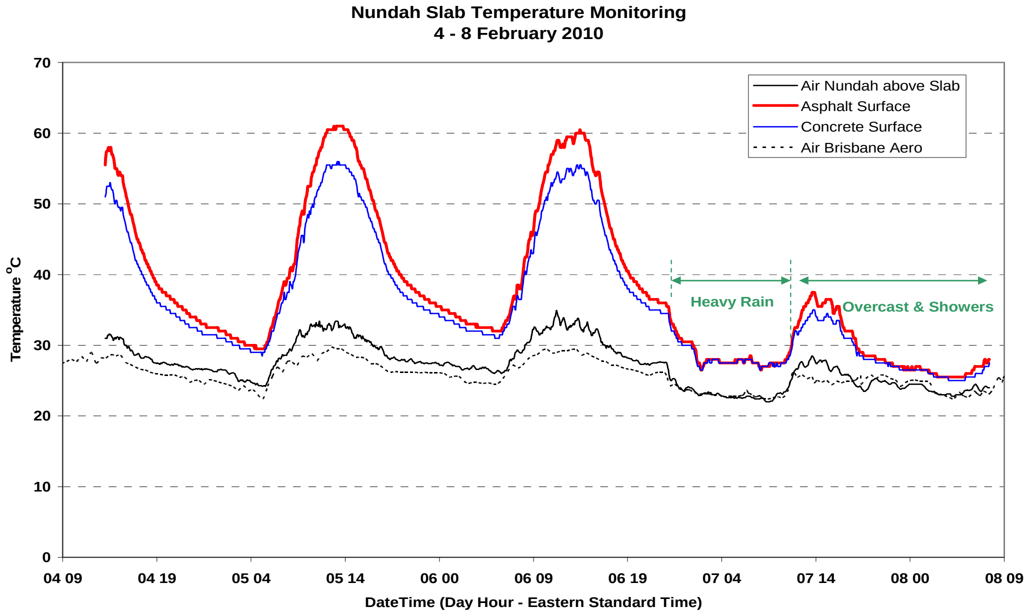


Figure 15: Temperature Conditions - Typical Hot Season Day – Brisbane

The results show that concrete surface temperatures are only slightly below asphalt surface temperatures. The following figure 16 plots the relationship between asphalt and concrete surface temperatures.

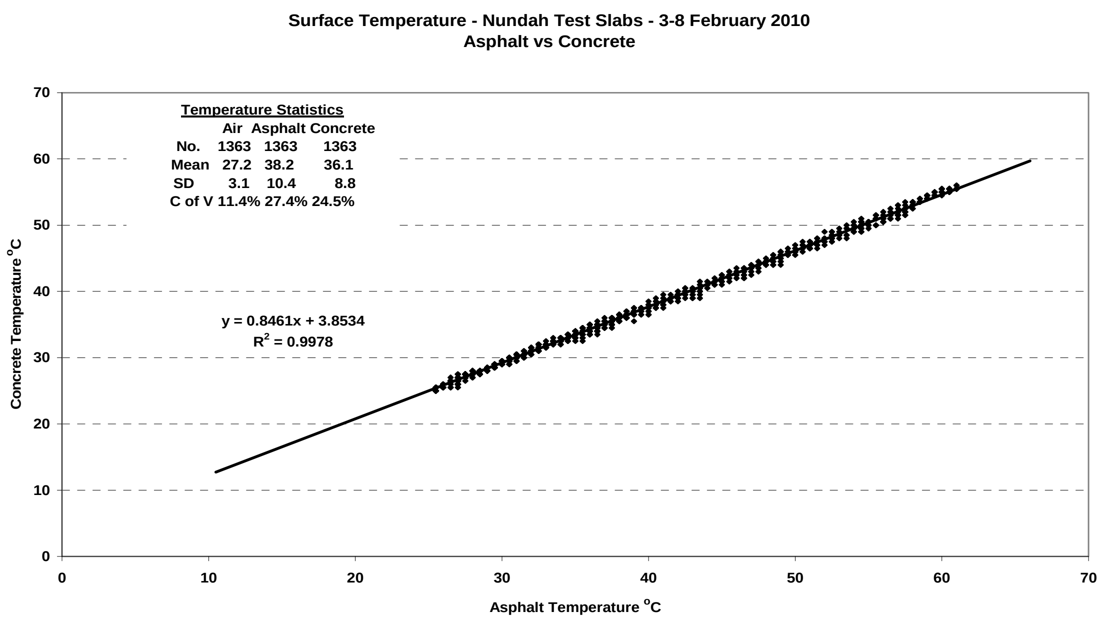


Figure 16: Concrete – Asphalt Temperature Relationship - Brisbane

Based on the above relationship, an asphalt surface reference temperature of 30oC equates to 29oC for concrete surfaces. The difference is not considered to be sufficient to warrant having a separate reference temperature for concrete surfaces.

SURFACE TEMPERATURE – F60 RELATIONSHIP FIELD TRIAL

General

Skid resistance temperature field trials are generally carried over time. This means that factors other than temperature can affect the skid resistance value. To minimise the influence of factors other than temperature, the trials conducted at the Nudgee Beach Road test site carried out over only two days (21 & 23 December 2009). The desired temperature ranges were achieved by commencing testing before dawn on the 21st and into the afternoon on the 23rd.

The Nudgee Beach Road test site is 1 km long, has a dense graded asphalt surface and is in an 80 km/h speed zone. The site is located on the western side of Schultz's Canal opposite Brisbane Airport as indicated in the following locality map.

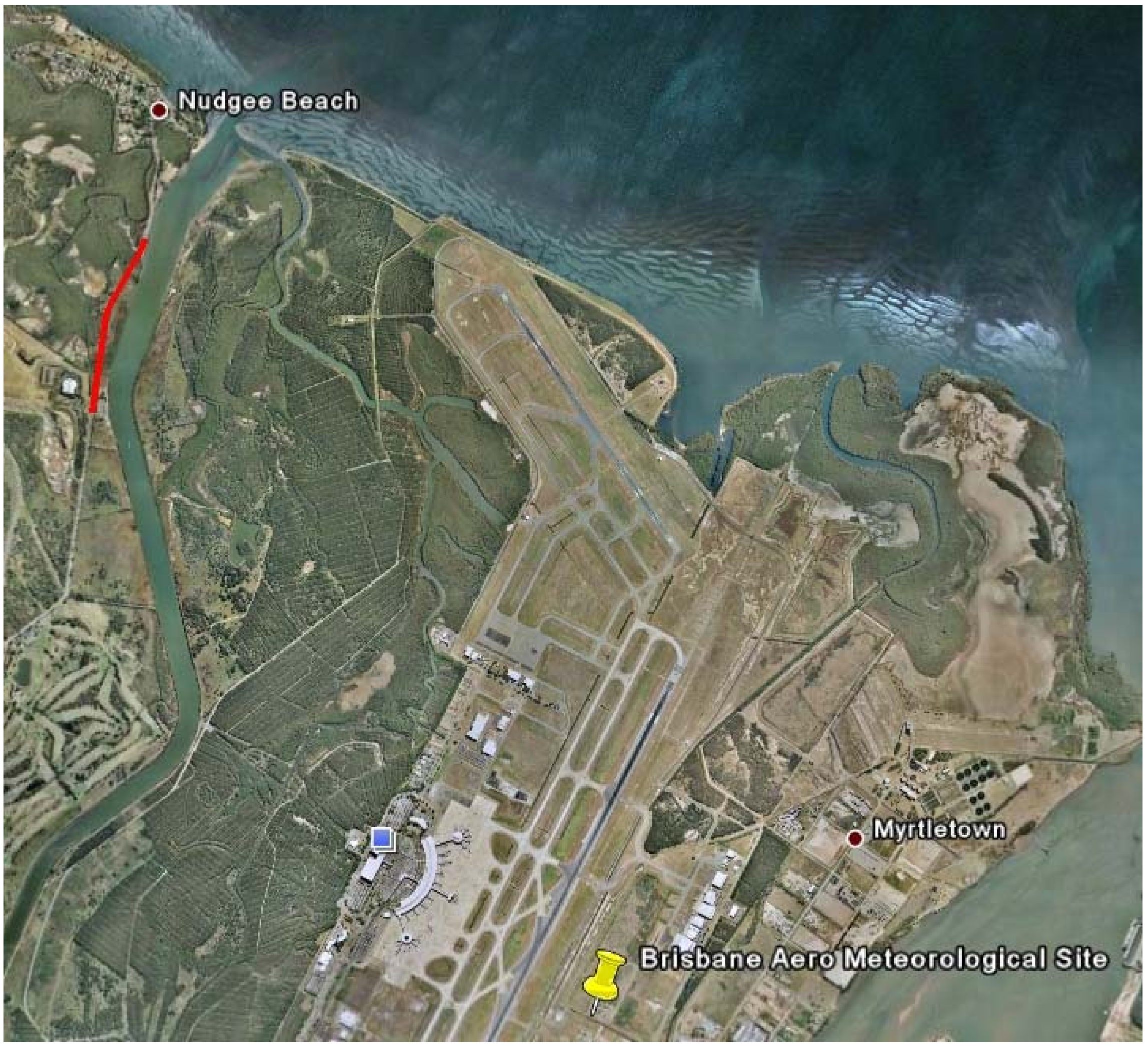
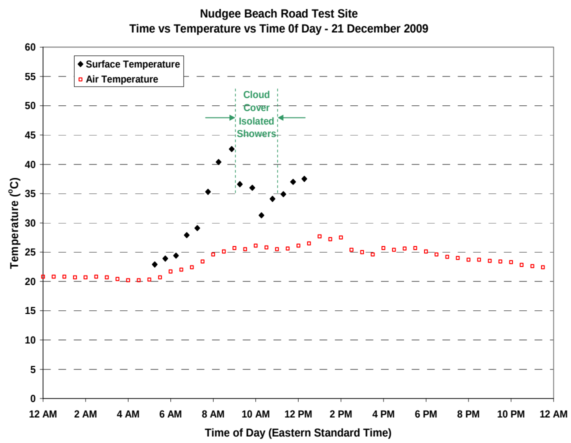


Figure 17: Nudgee Beach Road Test Site

Temperature Conditions during Field Trials

Surface temperature measurements were taken at the start of each skid test run using a hand held infra red temperature sensor. Hourly air temperatures, on the test days, were obtained from Australian Government Bureau of Meteorology (station 040842) located at the nearby Brisbane Airport. Figures 18 and 19 present this data.



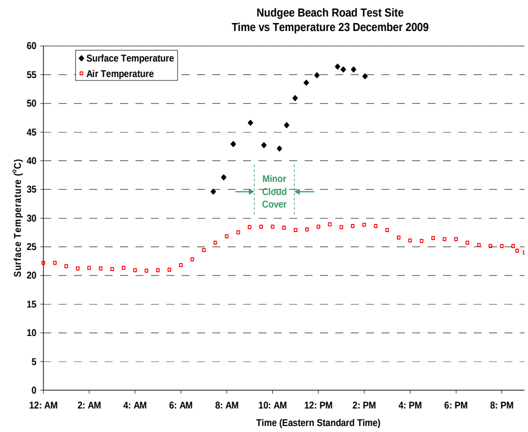


Figure 18: Temperature Conditions 21/12/09

Figure 19: Temperature Conditions 23/12/09

Skid Resistance Results

Skid resistance testing was carried out using our ViaFriction test unit. The unit was set to operate in continuous fixed slip mode with the percentage slip set at 75% to provide a direct reading of F60 at the set 80 km/h test speed. Where minor variations of the test speed occurred, the skid resistance value was adjusted using the following PIARC (1995) relationship and adopting a Sp of 80 for the asphalt. This Sp value had previously been determined for the site.

$$F60 = Fs \times e(s-60)/Sp$$

Where F60 = skid resistance at a slip speed of 60 km/h,

Fs = skid resistance at a the measured slip speed of s km/h,

S = test slip speed in km/h and

Sp = the speed dependency of the friction measure in km/h.

Testing was carried out in both the eastbound and westbound lanes with skid resistance recorded for every 10 m of each 1 km lane. The average skid resistance value for each lane was then determined and these results are presented against surface temperature in figure 20.

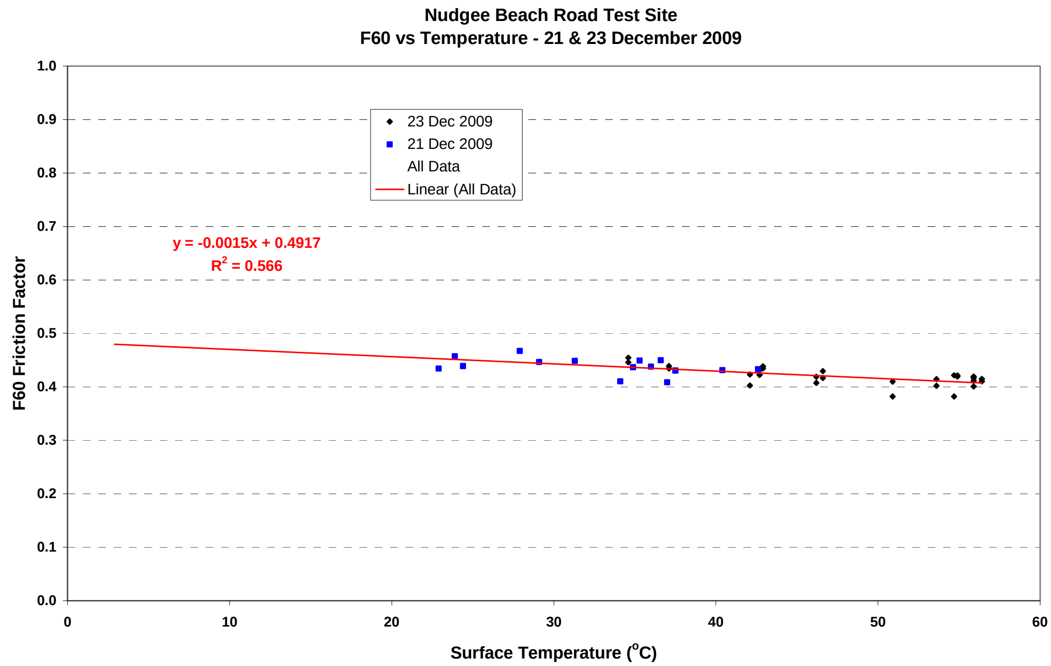


Figure 20: F60 vs Temperature

Temperature Correction Relationship

Adopting the above relationship and using a 30oC reference temperature, the following temperature relationship, for correcting F60 skid resistance measurements, can be obtained.

F60(30) = F60(t) + 0.0015(t) – 0.045

Where t = the surface temperature at time of test,

F60(t) = the recorded F60 at t oC and

F60(30) = the corrected F60 value for a 30oC reference temperature.

COMPARISON AGAINST CORRECTION FACTORS USED FOR OTHER DEVICES

For a comparison of temperature correction factors, all skid resistance results need to be expressed as a similar index. The pendulum and breaking trailer (locked wheel) devices express their skid resistance measure as a skid resistance number by multiplying their calculated coefficient of friction by 100. Similarly with SCRIM, their SR value is SFC x 100. The F60 temperature correction factors have to be multiplied by 100 for comparison with the other devices used in Australia and the US. These comparisons are presented in Figure 21. The US breaking trailer devices have been included because they operate at a similar slip speeds as the Queensland test units.

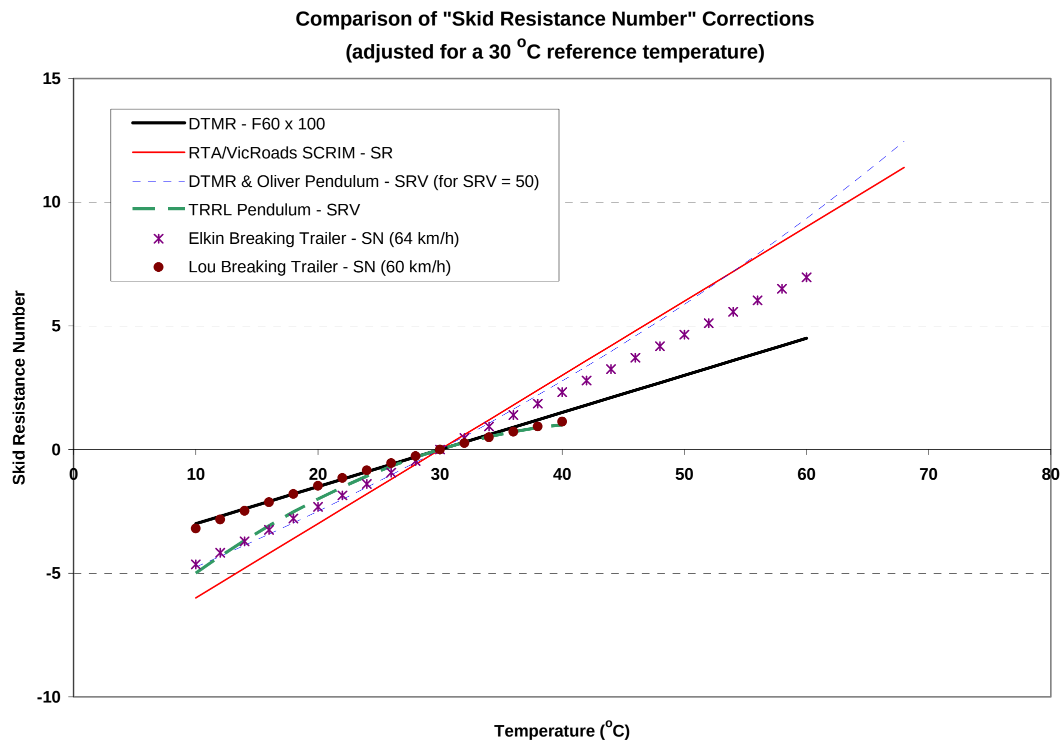


Figure 21: Comparison of Temperature Corrections

CONCLUSIONS

There is no unique relationship between air temperature and surface temperature for asphalt surfaces. Surface temperature is always greater than air temperature and the extent dependant on the number of daylight hours and cloud cover which control the duration of exposure to radiation from the sun.

As surface temperature is generally much greater than air temperature, it is considered to be the best measure to use for assessing temperature effects on skid resistance. Note:- The ASTM (1999) method appears to be primarily intended for testing of PAFV in the laboratory hence the use of an ambient 23 oC reference temperature is appropriate for this situation.

Although a 20 oC reference temperature, based on UK data, may be suitable for climatic conditions in Melbourne and Canberra, it is totally unsuitable for Brisbane where the surface temperature exceeds this level for 90% of the time.

The reference surface temperature for Brisbane should be 30 oC as these or higher temperature conditions exist for 51% of the time. This reference temperature has been used by DTMR since 1982 for temperature correction on Portable Pendulum test results.

Studies have shown that Townsville has similar surface temperature conditions as Brisbane. This is attributed to both locations experiencing the same amount of average daily solar exposure. The Australian Bureau of Meteorology annual average solar exposure charts appear to correlate with surface temperature regimes in Australia as reported by Dickinson (1981).

These solar exposure charts suggest that north west Queensland, the area west of the Charleville, Alpha, Hughenden, Georgetown and Weipa line (the 21 megajoules per square metre boundary), may have surface temperatures similar to Darwin where a reference temperature of 35 oC is indicated.

There is little difference in surface temperature conditions between thin asphalt surfaces and spray seals. Studies of surface temperature conditions in asphalt and concrete slabs at Nundah show that concrete surface temperatures are only on average 1 oC below asphalt surface temperatures and this difference does not warrant a change in reference temperature.

The temperature correction for F60 skid resistance measurements was found to be represented by the following relationship :-

F60(30) = F60(t) + 0.0015(t) – 0.045

Where t = the surface temperature at time of test,

F60(t) = the recorded F60 at t oC and

F60(30) = the corrected F60 value for a 30oC reference temperature

For north west Queensland, the following temperature correction is more applicable :-

F60(35) = F60(t) + 0.0015(t) – 0.0525

The temperature correction relationship for F60 correlates well with the Lou (2003) relationship for a US breaking trailer operating at a 60 km/h test (slip) speed.

These temperature correction relationships can apply to any braking force skid test devices that operate at slip speeds of approximately 60 km/h and which use the ASTM E – 1551 standard test tyre

The next stage of this investigation would be to confirm that the above temperature correction can be applied to spray seals.

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AUTHOR BIOGRAPHY

Ed has worked in the Materials and Pavements field with the Queensland Transport and Main Roads Department for the past 33 years. As Principal Engineer (Pavement Testing) he is currently responsible for the technical management of a specialist pavement testing service for the Department throughout the State as well as providing a routine pavement testing service for local Departmental Regions and Branches.

The Department's field test units provide a variety of unique test facilities to meet varied client's requirements from pavement investigation and pavement condition data collections to data input for rehabilitation design and specification compliance requirements.

In recent years, Ed has also been involved in the development, modification and upgrading of pavement test equipment, calibration and operational procedures including the commissioning of the new Network Survey Vehicles.