Roughening up a wet pavement surface!

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Synopsis

Road surfaces have to provide skid resistant surfaces in wet weather. It is well known that road accident rates increase in wet weather, and likewise runway overrun accidents significantly increase in wet weather. Research on factors affecting wet weather friction, and therefore safety, has enabled the identification of principal factors which are common to roads and runways. Runways experience higher speeds of operation and therefore are more demanding on such safety requirements. Relative to roads, runways have a much wider and flatter area to drain in wet weather. Runways have straight finite lengths while roads have curves with mostly continuous lengths. The specifications and recommendations of the International Civil Aviation Organisation (ICAO) provide a holistic approach to address the safe interaction between aircraft and runways in wet weather. On runways such a systematic approach incorporates long term performance of surface friction and smoothness specifications, while on roads such specifications tend to be handled more compartmentalised with less evidence of consistent systematic application. However, lessons learnt from development of measurement and control of wet weather skidding on roads had been shown to improve the holistic approach followed on runways by transfer of technology. The ICAO recommendations and specifications for wet weather wheel–surface interaction on runways are aimed at ensuring the four main aspects of good wet weather friction, namely; geometry, macro-texture, skid resistance (micro-texture) and adequate runway stop distance end areas are provided for. The matter is complex, and the systematic approach demands that all four aspects receive attention. It can be likened to the four legs of a table; - if one leg is missing, the table is unstable. Upgrades and rehabilitation of various airports in southern Africa are used as demonstrations as it represents the extreme case of wheel and surface interaction due to higher speeds of operation. Aspects highlighted, accentuate a need for a similar systematic and holistic approach to be followed on roads. Specifications for roads are examined and evidence of technology transfer to runways is illustrated.

Introduction

It is recognised (Austroads, 2005) that as well as concentrating upon a specific characteristic of a road surface (which is the main focus of this paper), road authorities can mitigate the incidence of crashes involving skidding by:

\begin{itemize}
  \item designing and managing a road network so that manoeuvres demanding high levels of skid resistance are avoided as far as possible through the disciplines of geometric design, and traffic and speed management;
\end{itemize}

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ensuring that the road surface is achieving an appropriate level of skid resistance and surface texture in practice, through the disciplines of inspection and maintenance activities;

being aware of highway management and maintenance activities that can impact upon the level of skid resistance generated at a location; and

e ncouraging and educating road users to operate well maintained vehicles (particularly with respect to tyres, brakes and suspension), and to moderate their speed in wet road conditions.

This paper links the technologies of runway skid resistance and road skid resistance. Vehicles and aircraft are both at risk of aquaplaning in wet weather when travelling at high speed. For cars with a tyre pressure of 220 kPa, aquaplaning can occur above 92 kph which is normally exceeded on freeways and highways. For aircraft with a tyre pressure of 1000 kPa, aquaplaning can occur above 167-185 kph (CAA RSA, 2010), and the typical touchdown speed upon landing is 250 km/hr (140 knots). Figure 1 shows by way of demonstration how the effective braking friction coefficients for a Boeing B737 reduces with speed on wet runways (NLR, 2001). Other surface contaminants, such as deeper films of water, snow and ice have even lower friction values at such speeds.

From South African road accident research, it is known that even though wet weather conditions occur only 2% of the time these periods can contribute up to 12% of total road accidents (COTO, 2008). This Pareto principle where wet weather occurrence is associated with most skid accidents is also applicable to runway safety situations. The higher speed of landing on a runway is the more extreme situation in wet weather and therefore will be used as a natural extension of extreme skid prone road conditions throughout in this discussion (Comfort, 2001 and NLR, 2001).

It is headline news when an airplane skids off a runway, and as a consequence, aircraft accidents are often more thoroughly investigated than most road accidents. The Civil Aviation Authority (CAA) normally takes the lead in such investigations. It is actually a complex set of investigations with stakeholders varying from officials, airport operators, airways operators, aircraft manufacturers, insurance companies, etc. Such investigations look at various aspects such as weather, operational procedures followed by air traffic control, pilot operational procedures, fire and safety operations, aircraft mechanical condition records and inspection, interviews with passengers, pilots, etc., as well as all the elements involved in the actual skid resistance of the wheel and surface interaction. Throughout the process of investigation records of all sorts and sources are examined ranging from the flight recorder (commonly known as the “black box”) to maintenance records of the airplane, etc. These investigations are normally done in a very systematic fashion and have added to our knowledge about wet weather friction which can be brought across to the road environment.
Only the aspect of the runway surface requirements is discussed in this paper to maintain common ground with the roads situation and not the other vehicle or aircraft and external factors. Most skid problems tend to occur in wet weather conditions which bring normal aspects associated with wet weather aquaplaning (also referred to as hydroplaning) into play. Aquaplaning investigations on runways normally lead to more detailed investigations into various categories of aquaplaning such as viscous, dynamic and reverted rubber aquaplaning (Comfort, 2001). Aquaplaning type is not discussed here, but rather the underlying surface factors which can lead to aquaplaning. Wet weather aquaplaning can become very complex and for that reason the airside pavement surface conditions are extensively described and specified by the main international governing bodies such as the various International Civil Aviation Organisation (ICAO, 1983 and 2004) guideline and design manuals.

A systems approach is followed during any investigation of the surface factors and is supported by the governing documents (ICAO and FAA) promoting such a systematic or holistic approach even in the design stage. Even though the language in the ICAO documents (1983 and 2004) vacillates between terms like standards and recommendations, the holistic intent is an integrated approach to safety in wet weather. Design documents for the road environment show awareness of the complexity of the total system or context, but for reasons of fear of delictual liability tend to shy away from lifting one specific factor out as a main contributor to skid problems (Stander, 1996).

Figure 1. Airplane speed versus effective braking friction coefficient for a Boeing 737 (NLR, 2001).
Systematic procedures followed during skid accident and overruns on runways investigations have led to the identification of four main factors in play during wet weather wheel-surface interaction. The four main factors of this holistic approach to tyre surface interaction in wet weather are the geometry, macro-texture, skid resistance (micro-texture) and safe run-off areas (termed runway end safety area or RESA in aviation). The matter is complex, and the systematic approach demands all four aspects receive attention and in context. As stated before, it can be likened to the four legs of a table which becomes unstable if one leg is missing.

The recognition of some the main features influencing skid resistance on road surfaces is illustrated in Table 1 below (COTO, 2008). The fact is however that these factors are not consistently, encompassing and holistic in their application as for runways. There are however aspects of the wet weather skid problem applied on road surfaces which can be applied to runway surfaces with clear improvement if linked to the holistic approach suggested incorporating all factors.

Table 1. Summary of Road Related Aspects Influencing Skid Resistance (COTO, 2008)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Influence on skid resistance</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface micro-texture</td>
<td>Higher micro-texture increases skid resistance</td>
<td>Important at all vehicle speeds. Affected by polishing of stone at high traffic volumes.</td>
</tr>
<tr>
<td>Surface macro-texture</td>
<td>Higher macro-texture increases skid resistance</td>
<td>Important at higher vehicle speeds (speeds greater than 80km/h)</td>
</tr>
<tr>
<td>Cross-fall</td>
<td>Higher cross-fall improves skid resistance in wet weather</td>
<td>Cross-fall influences the water film thickness on the road surface during rainfall. Thicker water films lead to reduced skid resistance. On roads this is normally 2% with some variation linked to super-elevation and road category.</td>
</tr>
</tbody>
</table>

Road safety is strongly associated with the wet weather surface friction and surface texture/roughness of pavements as stated before. The road texture and roughness therefore have a significant influence on wet weather skid resistance. The road texture and roughness therefore require proper definition. The Technical Committee on Surface Characteristics of Permanent International Association of Road Congresses (PIARC) (1995) classifies pavement surfaces in terms of relative wavelengths (λ) as shown in Table 2 to follow.

Table 2. Texture Classification of Pavement Surfaces (PIARC, 1995)

<table>
<thead>
<tr>
<th>Texture Classification</th>
<th>Relative Wavelengths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro-texture</td>
<td>λ&lt; 0.5mm</td>
</tr>
<tr>
<td>Macro-texture</td>
<td>0.5mm &lt; λ&lt; 50mm</td>
</tr>
<tr>
<td>Mega-texture</td>
<td>50mm &lt; λ&lt; 500mm</td>
</tr>
<tr>
<td>Roughness</td>
<td>0.5m &lt; λ&lt; 50m</td>
</tr>
</tbody>
</table>
The analogy of the four legs of the table will be used as applied in a systematic fashion for runways as framework of this discussion. As stated before the speed of operation on runways, as illustrated in Figure 1, is higher than that normally experienced on roads, although aquaplaning can occur on roads and runways alike. Therefore, it acts as demonstration of the extreme end of the operational action of the wheel and surface interaction in wet weather. As will be shown surface requirements for runways and roads are otherwise very much the same.

**Runway surface requirements**

**Geometry**

In the analogy mentioned above the first leg of the table is the geometry of the runway which should be such that its longitudinal and transverse alignment are without undulations or depressions where water can pond when wet, which is considered sound engineering practice on roads as well. The basic objective of the ICAO guideline and design documents (1983 and 2004) is to drain water off the runway in the shortest path possible and particularly out of the area of the wheel path. Considerable amount of water build up during even steady state rainfall conditions can occur and can be exacerbated due to transient effects such as winds and variation in rainfall rates. The surface geometry must therefore handle rather extreme conditions and be able to dry off quickly (Comfort, 2001). Adequate surface drainage is provided primarily by an appropriately sloped surface (in both the longitudinal and transverse directions) while providing a smooth surface. Unevenness can cause excessive bouncing, pitching, vibration, or other difficulties in the control of an aeroplane travelling at such higher speeds (See Figure 1). The same is true for roads even though speeds of operation tend to be lower. Such depressions created on a pavement surface can lead to ponding and ultimately to possible aquaplaning on runways and roads alike, but is exacerbated on runways by the higher speeds of operation (NLR, 2001; Comfort, 2001).

The basic geometric dimensional requirements for runways are linked to aircraft size, speed of landing and wingspan in the relevant FAA and ICAO specifications (de Neufville and Odoni, 2003). In general the geometric requirement for wide body aircraft, such as the Boeing 747 (ICAO class 4E) and the new generation super sized wide body aircraft, such as the Airbus A380 (ICAO class 4F) are higher than for the lower classes of narrow body aircraft. These two classes mentioned above respectively require 45 m and 60 m wide runways with the same requirements regarding cross fall, change in longitudinal gradient, etc. due to the higher speeds of landing. (ICAO, 2004, de Neufville, 2003) The normal highway with two lanes have total surfaced width of approximately 12.4m per direction which is considerably less surface area to drain than for the abovementioned runway situation.

The ICAO (2004) requirement that longitudinally no section of a runway (class 4E and 4F) the gradient should be more than 1.25% and the first and last quarters of the runway may not exceed a longitudinal gradient of more than 0.8% are super-imposed on the actual longitudinal gradient information of Hosea Kutako International Airport (HKIA), Windhoek in Namibia in Figure 2 (Horak et al, 2009). This is used as example to show that minor variations can produce ponding potential on such vast surfaced areas in the wet condition. The general slope of this runway is from the highest
point at km 0 sloping down towards the lowest point at km 4.5. That implies that water will tend to flow from left to right as shown in Figure 2 along the length of the runway. Figure 2 clearly illustrates that this runway’s threshold areas exceed the longitudinal gradient specification over the first quarters of the runway at both ends by being too steep. The longitudinal gradient tend to be much flatter over the middle half of the runway length, but there are also clear indications of slope change in a number of places. The added ICAO (2004) specification that slope transition over 30m should be less than 0.1% for 4E and 4F runways (not shown) is not met everywhere and therefore the runway has localised spots where temporary ponding can occur as indicated by the red rings in Figure 2. The cross fall of this runway is also flat and marginal and in combination with the localised longitudinal pond prone areas exacerbate the potential for ponding.

![HKIA Main Runway Longitudinal Gradient](image)

**Figure 2. Longitudinal gradient of HKIA main runway (Horak et al, 2009).**

The crossfall of HKIA hovers at approximately 1%, which is described by ICAO (2004) as the minimum for 4E and 4F runways. The “sweet spot” or maximum cross fall gradient value of 1.5% was derived by ICAO (2004) via experience as the central keel area (normally 11m both sides of the centre line) of the runway needs to drain as quickly as possible, to allow drier conditions on the keel area (where most of the aircraft traverse) than on the areas closer to the shoulders, and still provide for a relatively flat area for safe handling of the aircraft at the high speeds during landing and take-offs. It is significant that the cross fall gradient from the shoulders and further away from the centre line is specified as 2.5% maximum. This increase is clearly to help drain water away from the runway as quickly and efficiently as possible.

The cross-fall on the main runway of Bloemfontein Airport was 1.7% which exceeds the optimum of 1.5% and was recently lowered during rehabilitation actions of milling and infilling to the “sweet spot” cross-fall of 1.5% due to concerns of loss of control at high speed and skidding off a more steeply crowned runway in wet weather. Current rehabilitation of the HKIA runway is addressing mostly the cross fall problems by improving it from the approximately 1% cross fall to at least 1.2% and thereby providing an improved drainage situation with milling and inlay operations. A recent risk assessment study on another Namibian airport in the Namib desert, with a much flatter cross fall (average of 0.6%), has proven wrong the assumption made during the design phase that arid regions may warrant lowering of the ICAO (2004) specifications without impinging on safety risks, and in fact
the flatter cross fall increases the overall risk profile of such an airport significantly (Emery, 2009 and Horak et al, 2009). This tends to confirm the Pareto principle observed in the introduction with regard to wet surfaces, that many skid problems can occur even if wet periods are very limited in occurrence (PIARC, 2010).

The cross fall on roads (See Table 1) is clearly also designed to drain water off the travelled lanes as quickly as possible, but can generally be steeper than runways (2%) partly due to the easier control of vehicles travelling at relatively lower speeds of operation. However, freeways with multi-lane situations may often have sheet flow conditions akin to runways developing due to the longer lengths of the cross fall leading to accumulation of water. Such situations are often further exacerbated by superelevation changes on curves. The curving or meandering nature of the geometry of roads can lead to more complex problems of drainage than that of basically straight runways, and improved geometric specifications and measurement technologies have therefore been developed for roads which can only improve the monitoring and specification on runways if such technology transfer takes place.

Roughness measurement expressed in terms of the International Roughness Index (IRI) (m/km) for every 100 m of each wheel path is clearly a roads developed index (COTO, 2008) and is ultimately also geared at ensuring driver and passenger comfort with modern suspension systems adding to this focus on a smooth ride experience. The primary purpose of an aircraft suspension system, by contrast, is to absorb energy expended during landing. Airplane suspension systems have less capacity to dampen the impact of surface irregularities due to the magnitude of the energy that must be expended during landing. Runway roughness is therefore often defined in terms of fatigue on aircraft components (increase stress and wear) and/ or other factors which may impair the safe operation of the aircraft (cockpit vibrations, excessive g-forces, etc.) (FAA, 2009), and not in terms of driver and passenger comfort.

Runway roughness is considered in terms of single event bumps, and profile roughness. Various ICAO, FAA and aircraft manufacturers (e.g. Boeing) measures exist to quantify runway roughness, but related equipment is not always available in smaller markets like South Africa. IRI is not part of the ICAO specification, but roughness equipment used on roads is readily available. IRI application to runways provides indirect value to quantify smoothness, although has practical limitations due to the limited or finite length of a runway influencing acceleration to operational speeds and safe stopping distances of survey vehicles. A recent specification for an airport runway in southern Africa is shown in Table 3 to illustrate such an application. The average 100 m IRI for a “survey lane” is calculated by averaging the 100 m IRI left and right wheel path values as specified and the measurements should be taken immediately after completion of the runway construction. However, it is recognised that deterioration occurs over time and therefore measurements should be taken in years 1, 2 and 3 after the issuing of the Certificate of Completion to monitor the degradation trend as well. This latter aspect of deterioration monitoring is not clearly described in such detail in ICAO guidelines and therefore adds value to the holistic approach previously described.
Table 3. Acceptance criteria for IRI roughness values on a recent southern African runway

<table>
<thead>
<tr>
<th>Time (Years)</th>
<th>Limit Value (Average 100 m IRI)</th>
<th>Maximum (%) of 1 km Segment with Roughness Worse Than Limit Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.40</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>1.60</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>2.00</td>
<td>0%</td>
</tr>
<tr>
<td>2</td>
<td>1.60</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>1.90</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>2.10</td>
<td>0%</td>
</tr>
<tr>
<td>3</td>
<td>1.60</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>1.90</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>2.30</td>
<td>0%</td>
</tr>
</tbody>
</table>

The application of these criteria is illustrated in Figure 3 with the measurements on the recently upgraded Waterkloof Air Force Base main runway. In this case the higher resolution measurement of IRI/10m are shown (not 100m), but the criteria for the IRI/100m set in Table 3 after completion are superimposed to illustrate the smoothness achieved on this newly constructed runway. The start-up and slow down areas at the thresholds and run-off areas (Runway End Safety Area or RESA) clearly exceed the criteria, but are not representative measurements due to the limitations explained before.

Figure 3. Roughness measurement on the main runway of Waterkloof Air Force Base
Macro texture

The second of the four legs of the analogous table (holistic approach) is the macro texture requirements designed to meet minimum average texture depth limits. As shown in Table 2 macro texture is defined as the wavelength range from 0.5mm to 50mm. Macro texture is normally expressed in terms of mean texture depth (MTD) which is a three-dimensional quantity traditionally measured using a volumetric patch. Direct measurement is by sand patch, or grease method. Indirect measurement by various automated profilers is expressed in terms of mean profile depth (MPD) which is a two-dimensional quantity. A linear relationship exists between these two quantities (COTO, 2008).

Runways are often grooved to improve the macro-texture and to provide a negative surface texture versus the normal positive pavement surface texture. Measurement of texture depth for grooved surfaces is handled differently and it is not commonly used on road pavements, except in instances where super-elevation requires grooving to provide drainage of ‘flat spots’ or where the surfacing is noticeably lacking is macro texture.

Normally macro texture limits are time and deterioration linked. Macro texture is intended to provide paths for water to escape during wet weather under the wheel contact area during landing operations. FAA Advisory Circulars (1983, 2009) states: “The primary function of macro-texture is to provide paths for water to escape from beneath the aircraft tires. This drainage property becomes more important as the aircraft speed increases, tire tread depth decreases, and water depth increases.” The ICAO Design Manual (1983) clearly states in this regard “It should be clearly understood, however, that special surface treatment is not a substitute for poor runway shape, be it due to inadequate slopes or lack of surface unevenness” This emphasizes the interdependence of the legs of the table analogy. The following ICAO (2004) recommendation is given: “The average surface texture depth of a new surface should be not less than 1.0 mm.” and maintenance levels are specified acknowledging deterioration over time.

In Figure 4 the texture depth of various experimental sections on the runways of OR Tambo International Airport (ORTIA) (previously known as Johannesburg International Airport), are shown by way of illustration of both time and quantum linked to surface type effects (Joubert et al, 2004). It clearly shows that some surfacing types do not meet the 1 mm requirement directly after construction. It also confirms that there can be deterioration after a while. In this case open-graded type asphalt surfaces had texture depths after approximately 6 months drop even below the 1mm ICAO requirement. ICAO therefore specifies texture depth maintenance and rehabilitation trigger levels over time. Joubert et al (2004) also showed the negative effect of rubber deposits which tends to lower macro-texture due to clogging-up actions. ARCP (2008) states: “To make matters worse, the heat generated during the interaction causes a chemical reaction called polymerization that changes the rubber deposits into a hard, smooth material. This buildup of rubber fills the micro-and macro-texture of the pavement, causing a serious loss of skid resistance when the runway is wet; as a result, the rubber deposits must be periodically removed.”
Development of specially designed surface friction courses (SFCs) in the road environment (UKRB, 2005) has also found application on runways (Pretorius et al, 2007). Such surface friction courses are mostly proprietary ultra thin friction course (UTFC) which have led to the need to use the MTD or MPD as primary distinguishing factor for such ultra thin SFCs (Pretorius et al, 2007 and 2009 and Molenaar and Agema, 2009).

UTFCs are the cutting edge of technological development in surface friction courses (SFCs) and part of the collective group called Negative Texture Surfaces (NTSs). “The NTS family comprises a suite of proprietary surfaces, known collectively as thin surfacings and generic stone mastic asphalt.” This synthesis document on NTSs by UKRB (2005) also states : “The impact of NTS has been so great that some authorities have virtually ceased to use traditional rolled asphalt surfaces. The rapid introduction, however, has meant that there has been little time for longer term performance lessons to be learnt on the network.” The jury is therefore still out with regard to longer term durability and performance of NTS and specifically UTFC.

A specification recently used for an airport runway in southern Africa is shown below in Table 4. Mean Profile Depth (MPD) (ISO 13473-1) specified here is calculated for each 10 metres measured in the outer wheel path positioned 6 m left and right of the centre of the keel area of the runway. Output is presented as a cumulative distribution graph for each segment of 1km. This is again illustrating the improvement in specifications possible for runways, by transferring some of the concepts and technologies from the roads environment.
Table 4. Acceptance Criteria for Surface Macro-Texture on a recent southern African runway

<table>
<thead>
<tr>
<th>Time (^1) (Years)</th>
<th>Limit Value (Mean Profile Depth (mm))(^2)</th>
<th>Maximum (%) of 1 km Segment with Surface Macro-texture Value Worse Than Limit Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>1.4</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>1.3</td>
<td>0%</td>
</tr>
<tr>
<td>2</td>
<td>1.3</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>1.1</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>0.9</td>
<td>0%</td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>0%</td>
</tr>
</tbody>
</table>

In Figure 5 the MTD (sand patch methodology) shows how the application of a proprietary UTFC on Waterkloof Airforce Base meets the specification set in Table 4 after construction. The measurements on this UTFC will need to be re-measured in future to investigate if there is deterioration and whether it will still meet such set criteria. The threshold areas do not have UTFC surfacing, but new continuously graded asphalt explaining the dip in end values on the graphs in Figure 5. As benchmark the average MTD values on the secondary runway is 0.87mm with the lowest values 0.45mm illustrating the dramatic improvement experienced with the UTFC application. The secondary runway has an aged continuously graded asphalt surfacing. This surfacing will soon also be replaced with a UTFC as part of the upgrade and rehabilitation underway.

MTD measurement on the main runway of HKIA, Windhoek prior to rehabilitation were done on the aged continuously graded asphalt surfacing layer gave average MTD values of 0.7mm. This is clearly not meeting ICAO requirements and will soon receive the same proprietary UTFC that was applied on Waterkloof Air Force Base. As shown in Figure 4, even coarsely graded continuously graded asphalt surfacing types have low initial MTD values. Another recently completed Namibian airport has a new coarsely graded continuously graded asphalt surfacing with MTD values on average just below 0.5mm while values as low as 0.22mm were observed. This airport happens to have only 0.6% cross fall and a recent risk study (Emery, 2009) indicated that considerable risk can therefore be associated with such a runway surface condition.
Minimum macro-texture requirements are not consistently enforced on SA roads (Stander, 1996) in spite of the recognition given in Table 1 before (COTO, 2008). It does form part of toll road concessions as part of contractual obligations, but the focus is mostly a final outcome level at the end of the concession contract. This may be due to concerns about litigation potential and liability issues mentioned before (Stander, 1996). Minimum macro-texture specifications adopted in New Zealand is shown in Table 5 to follow. Indications are that these specifications are better enforced in New Zealand than in SA. As with the acceptance criteria for runways, recognition is given that MPD becomes less over time due to normal deterioration. However, as Table 5 shows, the required MPD on roads are relatively lower than for runways. This may be due to the higher speeds on runways, but UTFC usage on roads means that these criteria may be adjusted upwards as it can now easily be matched on roads as well.

The South African Roads Agency Ltd (SANRAL) has increased their specification for macro-texture lately in recognition of this aspect, but this does not cover all the road authorities at provincial and local authority level. The vast majority of surfaced road network in SA therefore suffers from inadequate specification and associated monitoring of macrotexture and it is common knowledge that general condition of the latter road networks are deteriorating due to lack of maintenance. The hazard of wet weather operation on roads is therefore not yet adequately addressed.

It is also clear from these MTD values achieved on runways that the trend to use UTFC on roads is more than justified in terms of the improved macro-texture values. It is suggested that the criteria set in Table 5 at least be applied more rigorously and consistently on SA roads. The next section on skid resistance will show that there are also dramatic improvements associated with the use of UTFC confirming the influential role of macro-texture in a holistic fashion is possible for roads.
Table 5. Typical macro-texture requirements for roads (Cook, 2005)

<table>
<thead>
<tr>
<th>Facility</th>
<th>Texture Depth (MPD, mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New Surfacings</td>
</tr>
<tr>
<td>Urban; Legal and operating speed equal or less than 50kph</td>
<td>0.5</td>
</tr>
<tr>
<td>Urban; Legal and operating speed equal or less than 70kph</td>
<td>0.7</td>
</tr>
<tr>
<td>Rural; Legal speed 70kph or higher</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Note: Values represent minimum threshold levels and not investigatory levels.

Skid resistance

The third leg of the analogous table is skid resistance. ICAO (2004) sets the following standard: “The surface of a paved runway shall be so constructed as to provide good friction characteristics when the runway is wet” The reason for this is clearly illustrated in Figure 1 where dry and wet surface skid resistance are shown versus speed for a Boeing B737 illustrating there is a marked decrease in effective skid resistance when the surface is wet or otherwise contaminated.

It is well known that under dry conditions, micro-texture is the most important aspect of skid resistance (COTO, 2008 and Comfort, 2001). However, in wet weather, the influence of micro-texture depends on how much water can be dispersed to ensure small scale asperities can break the remaining water film, thereby establishing the momentary bonds that contribute to friction. The ability to disperse water depends on the macro-texture and vehicle speed and the complex interplay between macro and micro-texture and the thickness of the water film.

In Figure 6 the basic trends illustrated in Figure 1 are confirmed for the roads situation by showing the combined influence of macro and micro-texture conditions with speed of vehicles (COTO, 2008). It is clear that at higher speeds macro-texture tends to facilitate the influence of different micro-texture combinations the most on skid resistance. Although both micro-texture and macro-texture levels are specified for roads, some countries, such as France, tend to specify only macro-texture levels while the quality of the micro-texture is governed by policies on the quality of the wearing course aggregate and surfacing type used (Dupont and Bauduin, 2005).
The French application of the Pareto principle recognising the influence of macro-texture on skid resistance and safety is borne out by the relationship in Figure 7 for roads (Viner, et al, 2004). Low MTD or MPD values (in this case expressed as SMTD) tend to correlate with low skid resistance values which in turn correlate with high accident rates. This is again testimony that the ICAO and FAA systems approach to wet weather skid resistance regulations also applies to the roads safety situation and control. It is therefore advocated that such a systems approach also be followed on roads when specifications are compiled.
Various surface friction measurement equipment are available in SA with various different attributes (COTO, 2008). It seems that there is no ideal measuring instrument currently available particularly if the different demands of roads and runways are weighed up (CROW, 2006). The Grip Tester is currently used regularly by road authorities in SA. The Grip tester can test at low as well as at higher speeds and have also been used on airport runways on an on and off basis. Unfortunately, because of the link with roads and other logistical reasons there has been a trend to measure mostly at 65 km/h on runways as normally done on roads. Such low speed Griptester measurement does not reflect the real problems at higher speeds of operation on runways. It is clear from Figure 6 that the influence that macro-texture can have on actual skid resistance at such higher speeds of operation may in fact be missed. However, in common with all such continuously measuring friction equipment, the results of the Griptester are not adequate by themselves to fully describe the wet weather friction characteristics of the pavement, and macro texture results are also needed.

In Table 6 a recent specification for 60kph and 95kph on an airport runway is shown. It specifies measurement at 1, 2 and 3 years after completion to accommodate deterioration. Data is recorded at 10m intervals as measured on the centre line and 6m left and right of the centre line. Figure 8 shows the centre line Grip Test number (GN) measured at 95km/h on both the main runway and the secondary runways of Waterkloof Air Force Base. It clearly shows that the UTFC on the new main runway meets the design criteria while the secondary runway surface is clearly in need of maintenance and rehabilitation. UTFC is not paved on the threshold areas and contribute to the dip in values seen at the ends of the main runway. The positive spike in the secondary runway
measurements is where it crosses the new UTFC repaired main runway. The secondary runway will receive a UTFC during the next phase of this rehabilitation and upgrade project.

Table 6. Grip Tester acceptance criteria for surface friction.

<table>
<thead>
<tr>
<th>Time (Years)</th>
<th>Limit Value</th>
<th>Maximum (%) of 100 Segment with GN Value Worse Than Limit Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grip Number</td>
<td>65 km/h</td>
</tr>
<tr>
<td>1</td>
<td>0.74</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>0.70</td>
<td>0.60</td>
</tr>
<tr>
<td>2</td>
<td>0.74</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>0.70</td>
<td>0.60</td>
</tr>
<tr>
<td>3</td>
<td>0.70</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>0.60</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Figure 8. Grip Test values for centre lines of main and secondary runways on Waterkloof Air Force Base

Skid resistance as measured and shown to be dependent on macro- and micro-texture of the aggregate clearly has a durability aspect not mentioned before which can also be specified directly. Polished Stone Value (PSV) is used on road surfaces due to the abrasive action of tyres on the aggregate exposed to identify specific road stones which will not deteriorate quickly over time in terms of their micro-texture. PSV limits have been specified for road stone (Stander, 1996) in SA as standard design input, but availability of such durable abrasive resistant road stones are often problematic and is selected stone is often marginal. Synthetic abrasive resistant aggregate is often used with polymer binders on “black spots” where there developed a track record linked to skid resistance incidents. In practice such material proved to be difficult to maintain due to their
specialist nature and application technology. Identification of “black spots” have recently also been put under pressure in SA as it is construed as associated with possible admission of delictual liability. Stone polishing is rarely a concern for runways because of the much lower volumes of traffic.

Roads are not always straight like runways for obvious reasons and meanders or curves due to the topography of the landscape, but it is significant that the sharpness of curves in the road combined with skid resistance shows that even good skid resistance on sharp curves cannot prevent relatively high accident rates. This relationship is clearly illustrated in Figure 8 to follow (Viner et al, 2004). Figure 9 serves to confirm the systems approach followed by ICAO and FAA on runways also hold sway for roads when it comes to safety due to other factors which must be viewed in terms of the total context of the safety situation.

Safe runoff distance

The fourth leg of the analogous table is the need for a safe run-off area. On runways, this is provided by a Runway End Safety Area (RESA) at each end. Normally safe stop distances, sight distances and run-off areas are aspects which are geometric design features on roads and are considered to prevent conflict between vehicles or obstructions. The closest comparison between roads and runways is the potential conflict situation at signalised intersections. A driver of a vehicle approaching a green light intersection goes through the “dilemma zone” (Stander et al, 1996), which, depending on the speed of approach, may or may not leave long enough stop distance before the
intersection, if the light turns red or amber at that moment. Speed restrictions are the main legal means to control this resultant stop distance needed on roads assuming all the other legs of the table is in place. The same “dilemma zone” exists on a runway during take-off for possible flight aborting. The remaining length of runway then becomes critical and is depend and on the three other legs of the analogous table for safe stopping before the end of the runway. The runway is of finite length with overrun implying not a potential conflict, but rather the need for a safe runoff area giving additional stop distance after the end of the runway. The RESA should therefore be seen as a last resort additional stop distance if there is an overrun.

ICAO (2004) requires a RESA to be at least a 90m extension from the end of the runway strip. It is recommended that a RESA be at least 240m in the case of runways for larger aircraft. The nature and description of a RESA is unique to runways and does not require the same structural strength or bearing capacity as the rest of the runway, with the possibility of aircraft even punching into the “softer” RESA pavement structure, aiding the stopping effort. Military airports often also have catch nets to catch an over-run airplane. Similar retardation devices are lately also nowadays considered in place of Arrester Beds on roads.

There are various factors that contribute to runway overruns (Emery, 2009). The amount of runway length available in excess of that required (landing distance required (LDR); or accelerate stop distance required (ASDR) when aborting during take-off). In Figure 10 the relative probability of over runs during take-offs is shown versus the ASDR required (Emery, 2009). The same type of probability curve can be calculated for landings. Such a relative probability was used as a basis for the calculation of an annual fatality risk for all overruns on a airport runway in Namibia, which was pointed out before to have poor geometry and friction/macro-texture features. The fatality risk value calculated in this case was 3.4E-06, which is two orders of magnitude higher than the preliminary risk of 3.6E-08 for this airport based on meeting ICAO standards for the defective geometric features mentioned above. The risk for any individual stage of a flight should be similar to that of other stages, which means that the risk of overrun should only be around the 1E-07 (1 x 10^-7) level (similar to a mid-air collision risk) (Emery, 2009). The addition of a runway surface friction layer would be needed to lower this relative risk to an acceptable level.
Conclusions and recommendations

Most wheel-pavement surface skidding problems are linked to wet weather conditions. It therefore allows for the application of the 80/20 rule or Pareto principle where the most influential aspects associated with such a situation can be identified and controlled.

When a skid related incident happens on a runway or a road surface it is standard practice to follow a process of systematic accident investigation. These Pareto principle factors are all investigated separately and collectively to determine possible cause and effect. It is therefore suggested that a systematic or holistic approach is needed in the design and management of pavement surfaces for safety purposes as the eventual investigation will follow such an approach in any case. The approach followed in the presentation was to use the analogous example of a table with four legs becoming unstable if even one leg is missing and acting as a total system to keep the table up and stable. The systems or holistic approach is also recognised in roads design standards, but increasing fear of delictual liability issues by SA road authorities tend to erode the needed holistic approach thus suggested.

Runway wet weather skidding happens at higher speeds than on roads and therefore acts as the more extreme condition of wheel-surface interaction in wet weather on roads as well. Runway features were therefore highlighted as the more extreme case in this discussion. Added to this is the
observation that the relevant airport and runway design and guideline documentation illustrate clear recognition of the systems approach needed with such identified main contributing factors.

It was suggested that the first leg of the analogous table is that of longitudinal and cross fall geometry which has the main intention to drain water during rainfall off the travelled way of either a road or runway in the shortest possible path. Optimal and safe gradients have been set for both roads and runways over time, which is not always adhered to due to other reasons which tend to compromise the safety condition. It has been shown that the direct geometric aspects specifications used on runways can be enhanced by using roads roughness measuring technology, IRI measurements, to evaluate runway smoothness. Recognition is also given that smoothness of a road and therefore a runway can deteriorate over time and therefore needs regular measurement to trigger possible maintenance and rehabilitation action.

It is common knowledge that apart from premier road authorities, like SANRAL in SA, who measure road roughness on a regular network basis, other provincial and local authorities have fallen way behind and may even not do it at all. Airports in southern Africa are under control of various authorities and agencies. There are also indications that this smoothness aspect is measured on an ad hoc basis and not measured on a regular basis as required by international guidelines and specifications. On runways undulations have the grave possibility of creating water ponding which can contribute directly to aquaplaning and skidding as many an investigation have shown in the past.

The second analogous table leg is macro-texture which is needed to provide for water to be dissipated under the travelling wheel in wet circumstances to provide for continued functioning of the micro-texture and related small scale asperities breaking the remaining water film, thereby establishing the momentary bonds that contribute to friction. Runways specify at least 1mm macro texture depth and few existing runway asphalt surfaces in southern Africa can achieve that value without specific adjustment, design or use of proprietary surface friction courses meeting such a specification. Of the latter UTFC, part of the new generation Negative Texture Surfaces (NTS), are replacing previous more finicky proprietary skid resistant surfaces with epoxy and polymers and is increasingly replacing other asphalt surfacings used as surface friction courses. As the jury is still out on the durability of these NTS type surfaces, measurements of macro-texture should be done regularly. It has been shown how UTFCs are used with good effect on runways while it has virtually become standard practice on roads.

Macro-texture also deteriorates with time and adherence to initial PSV alone cannot provide for durable macro-texture over time. On runways the added problem of rubber deposits makes regular cleaning maintenance actions on busy runways an imperative, while on roads PSV compliant road stone becomes an availability and associated economic cost which tend to be all too easily ignored due to other “larger problems”. The general deterioration of road networks in SA and proliferation of potholes on some of the provincial and local authority road networks have become the focus of everybody with clear delictual liability problems looming. This general deterioration of the road network has diluted the importance of aspects such as PSV and macro-texture for safe travelling in wet conditions. In short a pothole is perceived by the general public to be more dangerous than a smooth road surface!
The third analogous table leg is actual skid resistance which is largely speed, macro-texture and micro-texture dependent. Measurement of skid resistance is difficult to do on a full network of roads and is not even done as regular on runways as actually required and often not at the correct speed. There are concerns about appropriateness of available measuring technology and accuracy for both roads and runways and particularly if applied to both environments due to the difference in speed of operation. The measuring procedures for skid resistance are also expensive and it is difficult to apply the minimum standards in practice. Guidelines regarding minimum standards have been developed elsewhere with partial acceptance by some road authorities in SA. It is clear that general lack of maintenance on provincial and local government roads is again a distracting factor, but is in fact exacerbating delictual liability issues and potential for legal action by road users.

The last analogous table leg relates to last resort provision of adequate run-off areas when skidding in wet weather takes place. When actual braking happens in wet weather the first three legs of the analogous table will determine whether the plane or vehicle will be able to stop without skidding on the road or runway length left before end of runway or conflict at an intersection on a road. In the case of runways length is finite and a last resort RESA must be provided to ensure safe stopping of the plane when over shooting when skidding off the runway. In the case of roads a vehicle driver also faces a “dilemma zone” similar to a pilot contemplating abortion of a take-off manoeuvre, and adequate run-off areas, arrestor beds or catch nets/barriers must be provided. In general the road situation is at a disadvantage as an overrun due to skidding mostly implies conflict while on runways it implies adequate RESA length provision may still provide possible stoppage of the plane. On roads this stop distance is largely regulated by speed restrictions in urban areas and signal timing design.

Risk analysis studies on airports have been done and properly benchmarked with other catastrophic events with known risks. In general all elements of a flight can be compared with the risk for mid-air accidents. In this way it can be shown that wet weather, even if it is in a dry and arid region, will still adhere to the Pareto Principle of most skid accidents taking place in wet weather. Therefore if one or more of the legs of the analogous table is not in place the overall risk can become unacceptable even in a dry climate. There is a move in the roads environment to use risk assessment during construction and design, and this can be extended to the management and maintenance phases. This approach has not been done yet in SA for reasons primarily linked to the fear of delictual liability if such risks are known.

It is suggested that all roads (national, provincial and local government) are maintained and the Pareto principle followed in measuring the important aspects of wet weather skid factors. They act as a holistic unit and without all functioning properly will lead to failure and wet weather skidding. Accident investigations are done in such a systematic fashion and therefore fears of delictual liability on the side of road authorities or airport authorities cannot exempt them from the ultimate consequences if the needed pavement surface safety system is not provided or properly maintained.

References


CAA (RSA) (2010) Interim Report Number 2 in respect of the Investigation into the cause(s) of an Accident involving an Embraer 135-LR Aircraft, ZS-SJW during landing at George Airport on 7 December 2009. Accident and Incident Investigation Division, Civil Aviation Authority, Midrand, SA


FAA (1983) Airport Design, Advisory Circular, 150/5300-12, Federal Aviation Administration, Washington, DC


