APPLICATION OF INNOVATIONS AND LESSONS LEARNT ON A SINKHOLE PRONE RUNWAY RECONSTRUCTION

Bruce Morton[1] , Emile Horak[2] and Gert van Niekerk[3] Elsabe van Aswegen[4]

1. Competency Leader: Airports, Aurecon
2. Director KUBU Consultancy (Pty) Ltd, and office manager Ndodana Consulting Engineers ,South Africa.
3. Resident Engineer, Aurecon
4. Senior engineer, Ndodana Consulting Engineers (Pty) Ltd, Centurion, South Africa

SYNOPSIS

The main runway of Waterkloof Air Force Base was recently reconstructed and upgraded to overcome dolomitic sinkhole instabilities and meet international accepted standards. The airside is classified as high risk for sinkhole formation and therefore the performance management dictated that a risk management system be implemented in all facets of the design. The project involved deep excavation, dynamic and impact compaction and concrete raft construction in sinkhole prone areas. Drainage and stormwater management was integrated into the design. The runway width was widened not only to meet ICAO Code 4E requirements, but also to improve the longitudinal and cross-fall gradients to ensure safe and rapid water drainage. The existing pavement layerworks were recycled and used optimally to mitigate excessive new material resource requirements. The asphalt layers received special attention during the design and construction phase being an important aspect of the final durable waterproof surface required, with functional performance parameters developed for application of Ultra-Thin Friction Course surfacings on airports pavements.

1. INTRODUCTION

Waterkloof Air Force Base (WAFB) was originally developed in the 1940s and is located approximately 12km south of Pretoria Central Business District (CBD). The airport originally accommodated light fighter aircraft and since the early 1970s military freight aircraft such as the C-130s and C-160s were based at WAFB. The original airside pavement designs were for older, lighter aircraft and in spite of structural strengthening and overlays the main runway still possessed sections which could be classified as a light pavement structure. In the early 1990s the fighter aircraft were relocated and WAFB transformed into a Very Important Person (VIP) and freight movement base after 1994, becoming the facilitator for various international humanitarian relief missions for the rest of Africa and accommodating larger freight aircraft such as the Galaxy C5, Boeing B747, Iluyshin IL76 and Antonov AN124.

Over the years various upgrades and improvements have been undertaken at WAFB. The most serious problem for landside (buildings) and airside has always been the occurrence and potential for sinkhole formation. Runway 0119, as well as the secondary runway and large sections of the western taxiways (Alpha) and apron areas, are defined as Class 8, indicating high risk sinkhole formation potential for small, medium or large sinkholes.

Figure 1: Waterkloof Air Force Base

By 2006 it was clear that WAFB required upgrading. Two options were considered, namely to upgrade WAFB to accommodate newer wide body aircraft (i.e. transforming into a VIP and airfreight base facility near Pretoria) or to relocate the entire air force base to a new facility. Taking into consideration the strategic importance of the facility, its locality, the costs involved with the various options and the dolomitic mitigation actions required, national government approved the upgrade of the airside at WAFB. The construction of Runway 0119 represents the first phase of a planned USD 242 million upgrade of the airside facilities at WAFB.

2. DESIGN CHALLENGE

In the vast majority of runway reconstructions focus is placed predominantly on increased structural capacity with geometric improvements, functional runway surface properties and drainage of the runway strip playing secondary roles. In the case of WAFB the main design challenge to be overcome was how to design a flexible pavement structure for a 30 year design life spanning possible 10 m wide sinkholes developing directly underneath touchdown zones that experience dynamic loads in excess of 400 tons. A more inclusive design approach needed to be adopted that balanced water management, geotechnical conditions and a balanced, deep pavement structure while optimally reutilising existing material available within the existing pavement structure and subgrade and the adjacent runway strip.

Design risk management focussed heavily on the geotechnical investigations and associated designs. It was clear that stormwater drainage would need specific attention and for that reason the geometric design and pavement design also focused on associated improvements to mitigate drainage and water penetration concerns. Various recycled and waste materials were utilised in innovative manners to provide a well-engineered pavement without significant additional impact on natural material resources.

3. AIRSIDE LAYOUT

The airside of WAFB consists of two runways, primary Runway 0119 and secondary, cross-runway, Runway 0624. These are linked to the north-eastern and north-western aprons by a number of taxiways the most prominent being Taxiway Bravo extending the full length (and parallel to the east) of Runway 0119. Runway 0119 was originally designed as a Code 4E runway of 3,360 m length and 45 m width. The reconstructed runway would be designed to Code 4E (accommodate Code 4F aircraft) and be compliant to ICAO Category II precision approach landing requirements. Figure 2 illustrates the southern threshold (Threshold 01) of Runway 0119 with defined zones.

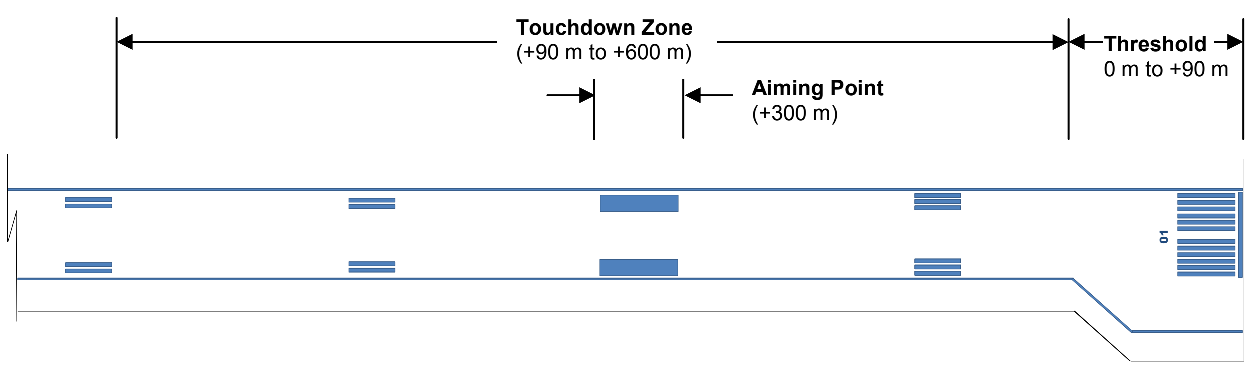

Figure 2: Schematic representation of Threshold 01 of Runway 0119

4. GEOTECHNICAL CONSIDERATIONS

4.1 Geology and in-situ materials

The various previous geotechnical investigations were analysed and the methodology of inherent risk classification (Buttrick et al, 2001) applied which produced a general map of risk classification areas. The runway threshold areas and general western area taxiways and aprons were classified as Class 8. This classification indicates high risk for small to large diameter sinkhole formation. Sinkholes (varying from 2m to 15 m diameter) have occurred on the landside and airside of WAFB.

The presence of water in pavement cracks after rainfall events and high natural moisture conditions in the soil alongside the runway prompted a more detailed geotechnical investigation. It concluded that Runway 0119 was in need of an engineered, substantial upgrade of the existing runway. Intervention was required to address the higher than normal moisture content of the pavement materials designed in such a way that it does not impact negatively on the dolomite stability.

4.1.1 Existing pavement structure

Table 1 describes the old pavement structure and description of the material type and general condition of the pavement layers. The thick asphalt layer (surfacing and base) consisted of a number of overlays. Cracks observed in this layer resulted in water intrusion into the lower pavement layers. The base layer consisted of either an old waterbound macadam layer over the original 2,700 m runway with a cement stabilised subbase on the southern extension (650 m in length).

Table 1: Original pavement structure description

Depth (mm)	Material Origin	Pavement Layer
0 - 200	Asphalt/Seals	Surfacing
200 - 300	Macadam base/ C2	Single sized 75mm aggregate (+650 to +3,360 m) C2 Cement Stabilised (0 to +650 m)
300 - 600	Chert Residuum	Sub Base (locally stabilized)
600 - 1000		Selected Layer (some stabilization noted)
1000 +	Fill (Aeolian & Chert Residuum)	Fill Terrace (Increases to 2.3m below surface at southern threshold, negligible at the northern threshold)

In general, the materials below the subbase exhibited very low densities, associated with poor compaction. Dry density values were highest in the upper 800 mm of the pavement profile, where Mod-AASHTO densities in excess of 95% were achieved in certain of the test results. However, the majority of tests undertaken show that density of the lower pavement layers was below 93% Mod-AASHTO, with numerous results below 90% Mod-AASHTO encountered.

The in-situ or field moisture content (FMC) of the various in-situ horizons/pavement layers was higher than optimum moisture content (OMC) of the material as illustrated in Table 2. It was observed that moisture contents outside the pavement prism area on the shoulders were higher due to lower and variable density conditions and linked with the poor stormwater system and wet services condition.

Table 2: Moisture content of in-situ layers

Horizon/Layer	% points FMC > OMC
Aeolian deposits	3%
Selected Layers (from Aeolian deposits)	1%
Selected Layers (from Chert residuum)	1%
Ferruginised Aeolian deposits	4%

The pavement structure could be defined as a relatively thin pavement structure for the heavy, large bodied aircraft operations undertaken at WAFB. The lower layers densities were suboptimal with higher moisture content than ideal under such high risk dolomitic conditions.

5. RUNWAY DESIGN

5.1 Design objectives

The design objectives of Runway 0119 can be summarized as follows:

(i) Integrate dolomitic mitigation measures with respect to services management
(ii) Ensure sinkhole protection (10 m diameter with complete loss of support) within critical zones including a monitoring system
(iii) Geometrically design Runway 0119 to conform to International Civil Aviation Organization (ICAO) specifications
(iv) Provide pavement structural capacity for a 30-year design period based on proposed aircraft operations
(v) Optimise pavement structural strength based on anticipated aircraft operations
(vi) Provide improved functional parameters of riding quality and skid resistance

The developed solution entailed the integration of improved compaction, provision of raft foundations and a balanced pavement structure in conjunction with a comprehensive drainage and ancillary services design.

5.2 Substructure design

The geotechnical design of the runway substructure consisted of 5 primary tasks:

(i) Mass excavation to depths varying between 3.5 m and 2 m dependent of risk classification and mitigation measures
(ii) Dynamic Compaction (DC) in combination with Impact Compaction (IC) of the various risk classifications utilising recycled concrete and macadam material
(iii) Construction of raft foundations on the thresholds
(iv) Installation of a High Density Polyethylene (HDPE) stormwater system
(v) Controlled fill and selected layers from stockpiles and imported slag material

Figure 3 provides a schematic of the cross section of the two predominate substructure designs applied to Runway 0119 based on the dolomitic risk class and loading characteristics. Over the landing zones of Runway 0119, which also represented the highest dolomitic risk, cross-section Type 1 was constructed, while cross-section Type 2 was applied over 80 % of the central runway section extending from + 540 m to +2,850 m.

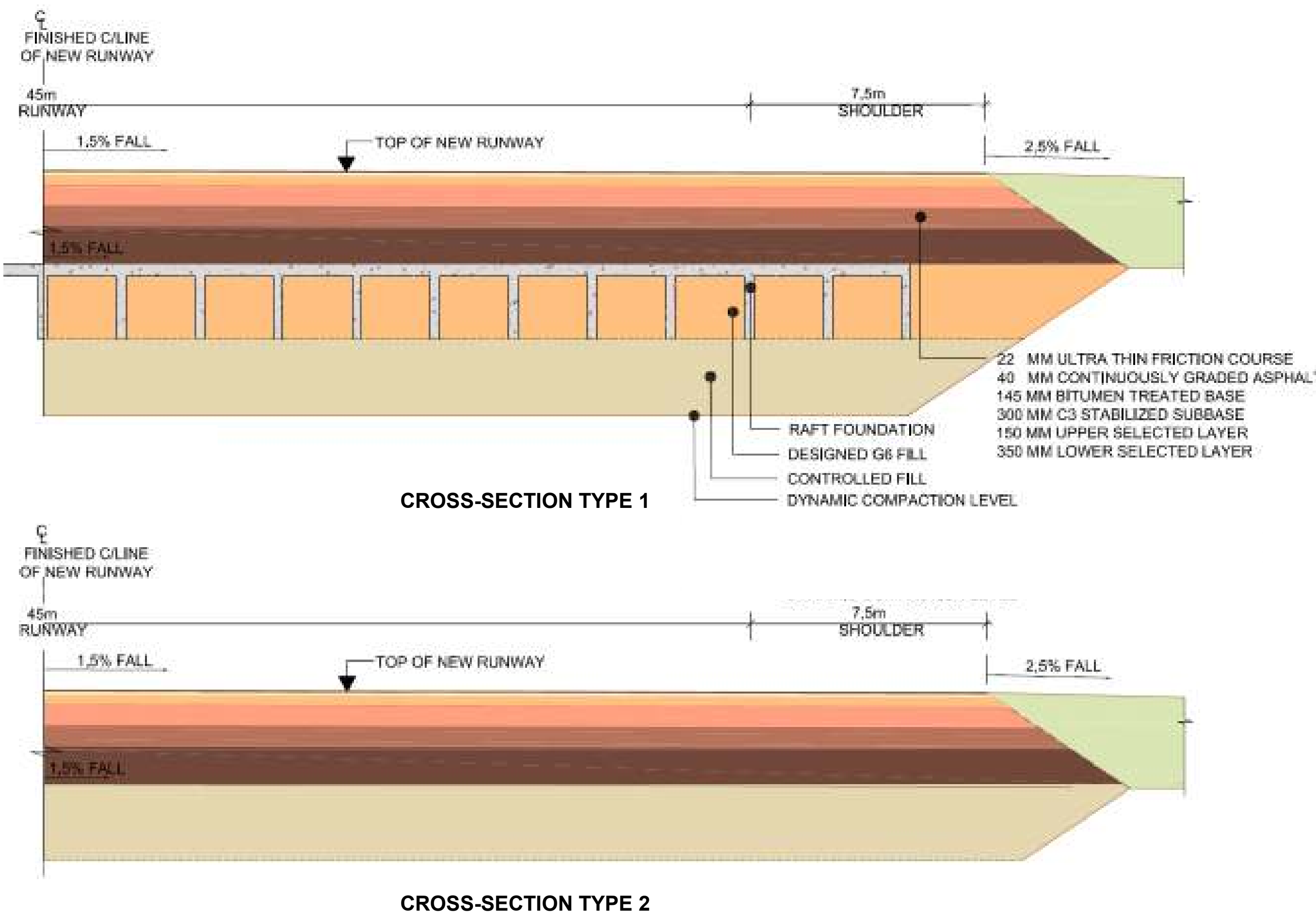

Figure 3: Substructure design incorporating raft foundation

5.2.1 Dynamic compaction

DC was achieved by applying weight drops of 12 tonnes through an 18 m drop height. The process comprised of primary compaction applied in a grid pattern of 5 m x 5 m, followed by secondary compaction applied in the same grid pattern but at an offset from the primary grid, completed by finishing or ironing. Primary and secondary compaction weights were rectangular (1.2 m^2 in area) while the ironing weights had a larger diameter (2.5 m^2). Ironing compaction was applied with 50% overlap of each weight drop. At the height of construction 15 cranes were utilised on WAFB to undertaken the DC.

At Threshold 19 (northern threshold) the DC comprised of a single pass of 15 blows each for primary and secondary compaction, with some isolated areas requiring an additional 5 blows, and ironing for the first 500m. DC at Threshold 01 (southern threshold) was more extensive, resulting in up to four passes of primary DC before continuing with secondary DC. The coarse aggregate of the Waterbound Macadam was found to be suitable as stone column filling material in the settlement holes, thereby recycling the material. The same principle was followed for secondary compaction, requiring up to three passes of DC. Both threshold areas were filled with a G6 quality material after DC and compacted with IC and normal roller compaction to at least 93% Mod AASHTO density. For areas requiring subgrade structural improvement rockfill was created through the recycling of approximately 1200m^3 of old concrete slabs demolished from the thresholds.

Figure 4: Dynamic Compaction in progress

5.2.2 Concrete rafts

The preliminary design for the threshold areas proposed rock/earth mattresses after deep in-situ dynamic compaction. However during the detail design a system of concrete rafts were designed to improve risk management. The ribs were designed to be 250 mm wide x 1m deep and the waffle core was 2.5m x 2.5m and a 200 mm slab. The rafts were constructed in 55m x 55m large monolithic continuous slabs. These represent the largest in-situ raft foundations constructed in a single pour operation within southern Africa. A total of 8 and 9 rafts were cast under the northern and southern landing zones, respectively.

The existing pavement selected layers were recycled through crushing and screening to produce a -19 mm G6 material for construction of a 1 m thick lower selected layer subbase. Thereafter the rib space was excavated with a ditch-witch to a 50mm tolerance. During the height of the rainy season the 2.5m X 2.5m inner G6 islets were protected with plastic covers. The fixing of the steel proved to be a logistical challenge, complicated by the in-situ soil formwork. Once the steel had been fixed the pouring of the 55 m x 55 m slabs was undertaken over a 12 hour shift with increasing speed and efficiency of the complex operation. Following the initial curing accomplished through a combination of continuous wetting and application of curing compounds, the completed raft slabs were covered with a loose layer of the G6 material previously removed from rib channel excavation operation to undergo further curing.

Figure 5: Concrete raft foundation reinforcement

A system of strain gauges was installed in the raft slabs to monitor strain and settlement. A total of 16 strain gauges were installed into each raft foundation. A fibre-optic communications system was installed between the raft foundations and the Air Traffic Control (ATC) tower.

The strain gauges will be calibrated against the aircraft operational loads in order to provide an early warning system of possible loss of support (excessive strain measurements) under the raft foundations. At the completion of phase 2 (under construction) and the installation of airfield ground lighting and remaining monitoring systems, the strain gauges will provide real-time information to the ATC of raft reaction to aircraft landing. This strain gauge monitoring system is supplemented by precise level monitoring at 224 specified locations along the length and width of the runway.

5.3 Support Layerworks

During the reconstruction of Runway 0119 the mass earthworks and layer works quantities amounted to approximately 750,000 m^3. The significant variation in soil conditions over the runway excavation, and the material generated from the reworked runway strip, necessitated the accurate assessment of material quality and appropriate reuse to optimize the utilisation of each material. To mitigate environmental impact of material import coke-oven iron slag was utilized for the majority of the material import requirements.

Table 3: Material utilisation summary

<table>
<tr><th>Material Type</th><th>Quantity (m^3)</th><th>Processing</th><th>Re-utilisation</th></tr>
<tr><td>Rock</td><td>4,250</td><td rowspan="3">Crushing
Screening</td><td rowspan="4">Dynamic compaction
Rockfill
Pioneer layer</td></tr>
<tr><td>Concrete pavement</td><td>45,000</td></tr>
<tr><td>Concrete pipes manholes and channels</td><td>6,750</td></tr>
<tr><td>Macadam</td><td>33,000</td><td>Screening</td></tr>
<tr><td>Asphalt</td><td>35,500</td><td rowspan="2">Crushing
Screening
Mixing</td><td>Shoulder base layer</td></tr>
<tr><td>C2 Base</td><td>6,750</td><td>C3 subbase</td></tr>
<tr><td>In-situ soil</td><td>625,000</td><td>Screening
Mixing</td><td>Raft foundation
Bedding layer
Fill
Runway strip
Soilcrete slurry</td></tr>
<tr><td>Slag</td><td>38,000</td><td>Mixing</td><td>Selected layers</td></tr>
</table>

All excavated material was stockpiled. Dependent on its characteristics the material was excavated, crushed, screened, mechanically mixed and reworked in order to produce the required material quality for each specific application. No material was spoiled from the site. Through the comprehensive classification, mechanical modification and optimal reuse of all excavated material 101,500 m^3 of additional imported material was averted, representing a cost saving of USD 1.05 million to the overall project cost.

5.4 Pavement design

The longitudinal alignment of the old runway was improved to comply with ICAO Annexure 14 specifications (ICAO, 2004) which led to the southern threshold being lifted approximately 1.6 m above the existing threshold level. The pavement design makes use of a strengthened keel design approach. A strengthened keel design optimizes, and focuses, the structural strength on the runway in areas that are exposed to the most excessive loads and the highest load repetitions.

In order to determine the keel dimensions the anticipated aircraft operations, with their respective landing gear configurations, were extensively modeled utilised AeroTURN to define the critical load areas of each airside pavement. Utilising the strengthened keel methodology and variable support layers a total of 11 different pavement designs were implemented in the reconstruction of the airside pavements at WAFB, five of which were utilised for the construction of Runway 0119. The keel section experiencing the majority of load (extent and frequency) is defined as the central 22 m of the runway.

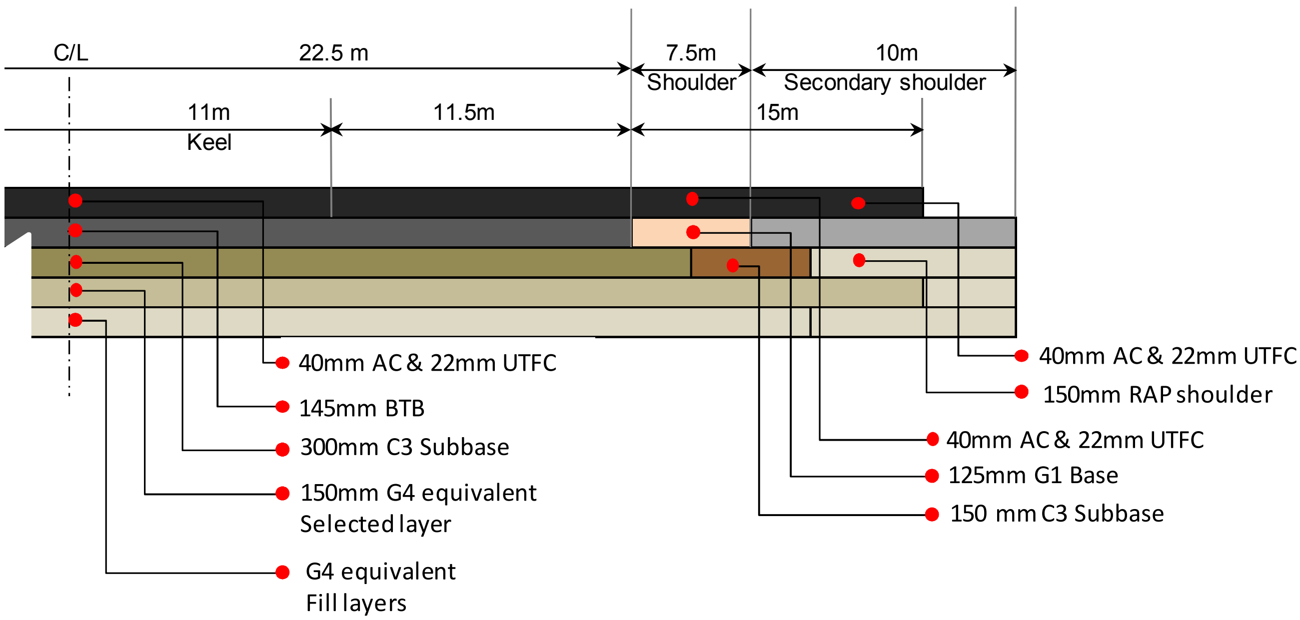

Figure 6: Runway 01119 pavement design

The deep compaction over the runway midsection and the concrete rafts under the landing zones provided for the construction of a deep, strong and well-balanced pavement. The design aircraft used was the Boeing 747, but the current C130 transport aircraft was also tested in the design analyses. Various software packages including as FAARFIELD, APSDS, ELMOD, RUBICON and ME-PADS were used in a triangulation approach to arrive at a risk managed pavement structure, meeting typical FAA and ICAO design standards.

Although the design aircraft for the pavement design is categorized as a Code 4E, the possible accommodation of the Airbus A380 and future generation large transport aircraft was taken into consideration. The pavement structure was designed using a strengthened keel approach in order to accommodate Code 4F aircraft.

The improved deep compaction and lower subgrade support resulted in the subgrade being classified as a G5/G6 quality material. This was an improvement on the originally specified G7 material. The runway selected layers were also mechanically modified with coke oven slag. The slag material can, with proper grading and selection, be constructed to G2 quality (Horak and Maree, 1982). In the mechanical modification of selected G6 material it improved the material to the equivalent of a G4 material quality.

The C3 subbase, constructed from the recycled C2 base and mechanically modified with imported G4, was stabilised with 3.5% cement to provide a UCS of 2 to 3.5 MPa at 100% Mod AASHTO compaction. Structural evaluation with the Falling Weight Deflectometer (FWD) at this stage of construction confirmed this deep and strong pavement substructure and a detailed FWD survey on completion proved that the total pavement structure was strong and well-balanced.

5.4.1 Asphalt layers

5.4.1.1 Bitumen Treated Base (BTB)

Investigations of recently rehabilitated airport runways have indicated that environmental factors tend to have a higher impact in terms of durability and permeability than actual traffic induced forms of distress such as shear deformation (Emery, 2005 and Cooley et al, 2007). The BTB was therefore designed with a 60/70 Penetration bitumen binder and was placed in two layers to maximize compaction efficiency. Minimum densities of 95% or 97% of the theoretical maximum density minus the numerical value of the percentage design voids (Marshall or modified Marshall) were achieved with careful consideration to compaction effort and technique. Special attention was paid to joint construction and first paver lane edges were cut back at least 2x layer thickness or 75mm. The binder content (BC) of 4.7% (volumetrically verified by gyratory testing) was deliberately allowed to be at least 0.3% higher than laboratory design optimum to ensure a thick film thickness and air voids was targeted to be on the lower side of the specified 3% to 6.

5.4.1.2 Continuously Graded Asphalt (AC) surfacing

The 40 mm asphalt surfacing was constructed with 3% Sasobit modifier and 5.2% BC. This was undertaken to ensure that higher and more uniform compaction could be achieved than the specified 93% minimum Marshall density. It is recognised that continuously graded mixes tend to become permeable from 7% to 8% air voids depending on maximum stone size and lift thickness (NCHRP,2006). The air voids were narrowed to 3% to 5% to encourage a lower than normal air void content. This was undertaken to encourage an impervious asphalt surfacing layer and to provide higher fatigue resistance to environmental deterioration.

The fact that the keel areas (generally defined as central third of full runway width) of the busiest airport runways in the world also have approximately ten times less traffic than a high volume freeway (Cooley et al, 2007) contributed to this high density approach where structural cracking and shear deformation are not a first forms of distress. Two separate standard penetration binder mixes were utilized for the first shoulder and second shoulder AC layers. The first shoulder (45 m to 52.5 m offset) was constructed from a medium continuously graded mix with a BC increased by 0.5% above optimal while the second shoulder (52.5 m to 60 m offset) was surfaced with a fine-grained continuously graded mix with BC 0.6% above optimum design mix BC. The compaction of the off-keel runway and shoulder areas was monitored to ensure that air voids approached the 3% rather than the 5% specified limit.

5.4.1.3 Ultra-Thin Friction Course (UTFC)

A proprietary UTFC of 22 mm thickness with a maximum aggregate size of 7mm was applied over the runway width of 45m. This mix design is an evolution of the mixes utilised on Bloemfontein and Kimberley airports by the Engineers. The UTFC provides improved skid resistance and macro texture in comparison with the more traditional surfacing utilised for runways. Detailed analysis of the layer thickness via 25mm diameter cores indicated that the layer thickness achieved was in fact an average of 25mm. Based on the experience gained on the BTB and AC layers special attention was given to longitudinal joints. It was specified that the cold edges be cut back with a milling machine to ensure that straight edges and optimum compaction was achieved next to the cold joint, as well as to provide a smooth joint interface.

5.5 Stormwater drainage

The complete redesign of all airside drainage was undertaken to mitigate the possible occurrence of sinkholes due to water penetration. The stormwater system consisted of HDPE stormwater pipes with heat welded joints, as well as HDPE manholes. This high specification system was selected to prevent any water intrusion via cracks or leaking joints. HDPE pipes of diameters between 300 mm to 1800 mm were installed at 75 m off-set from the runway and taxiways centerlines.

The ICAO Annexure 14 standards and recommendations were applied meticulously to ensure longitudinal drainage, as well as cross-fall drainage, were achieved by the shortest possible drainage paths. The cross-fall was set at the “sweet spot” of 1.5% cross-fall over the surfaced area of the runway. The runway width of 45 m with 7.5 m constructed primary shoulders each side brought the total paved width to 60 m to accommodate ICAO Code 4E wide body aircraft. An additional or secondary surfaced shoulders of 7.5 m was also added but with a cross -all of 2.5% to accelerate the water flow away from the runway. Hereafter the grassed strips dipped at 5% over the first 3 m and thereafter a consistent cross-fall of 2.5% was maintained to the catch pits 75 m away from the runway centerline.

The secondary shoulder areas were surfaced to increase the impervious area. This was achieved by recycling the considerable recycled asphalt pavement (RAP) from the old runway base and surface as a 150 mm G6/RAP layer which was compacted to 95% Mod AASHTO. This secondary shoulder was surfaced with 20 mm continuously graded asphalt effectively extending the surfaced area to 75 m wide ensuring water is transported over a wide area of impervious surfacing before being transported rapidly to the drainage points 75 m away from the runway centerline.

6. STRUCTURAL AND FUNCTIONAL PERFORMANCE MEASURES

6.1 Structural Performance

6.1.1 Deflection measurement results

Falling Weight Deflectometer (FWD) measurements were undertaken at various stages throughout the construction of Runway 0119 as proofing of structural integrity. A deflection bowl parameter benchmarking method was used to evaluate the relative structural strength of the reconstructed runway (Horak and Emery, 2009) and to assess the effect of employing a keel design methodology. The Base Layer Index (BLI), depicted in Figure 7, clearly indicates the stronger BTB layer of the keel area, the 'weaker' G1 base layer of the shoulder and the 'poor' base of the secondary shoulder. The structurally weaker shoulder areas correlate with the structural design philosophy for these basically non-traffic areas of the runway.

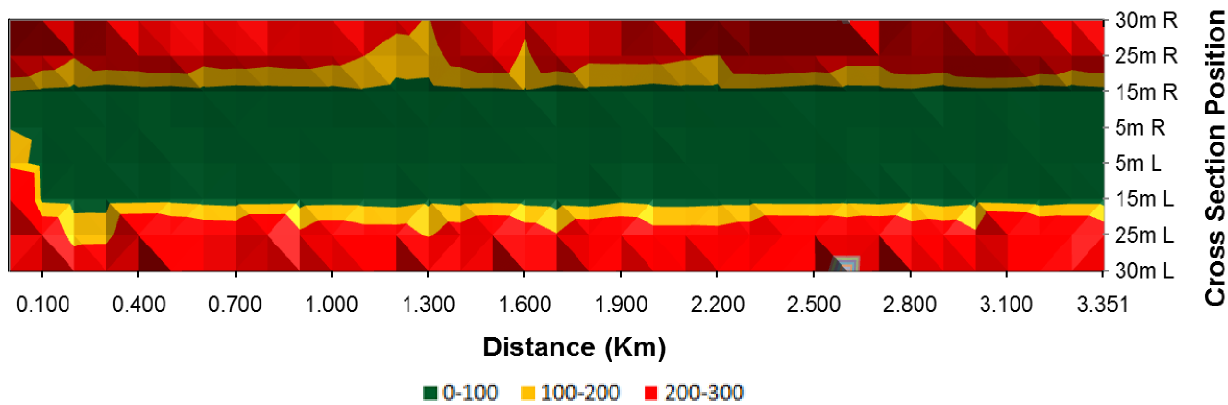

Figure 7: Runway 0119 BLI benchmark isograph

6.1.2 Pavement Classification Number

Pavement Classification Number (PCN) is a number expressing the bearing strength of a pavement for unrestricted operations. Pavements deteriorate gradually under the effects of loading and climate. Both the size of the loads and the number of load repetitions are important for the rate of deterioration. The PCN of a given pavement structure will, therefore, depend not only on the pavement structure itself, but also on the expected number of load repetitions.

PCN is generally expressed based on a uniform subgrade condition varying from a California Bearing Ratio (CBR) of 3 to 15. Due to the extensive earthworks and deep balanced pavement structure of Runway 0119, the subgrade CBR is categorized as 35 – 40. Utilising this subgrade CBR in conjunction with the deflection measurements provides an unrealistic measurement of PCN for a Boeing 747-400 design aircraft (200+). Manipulating the computation of the Pavement Classification Number to utilise a subgrade CBR of 15 provides a PCN value of 90 which allows for unrestricted operations of all current aircraft operations inclusive of the Airbus A380.

6.2 Smoothness and riding quality

The Federal Aviation Administration (FAA) and ICAO stipulate stringent specifications regarding longitudinal grading and smoothness (FAA, 2006 and ICAO 2009). For that reason International Road Irregularity (IRI) measurements were recorded and evaluated against the following ICAO recommended acceptance criteria:

(i) Maximum IRI = 2 mm/km
(ii) 95th Percentile IRI < 1.6 mm/km
(iii) 80th Percentile IRI < 1.4 mm/km

Figure 8 illustrates the average measurements per 100m readings for Runway 0119. It clearly indicates the exceptional riding quality achieved. This can be attributed to strict level control throughout the construction process with laser leveling utilised on graders and during paving operations. This ensured that the tolerances of the BTB and AC layers were within 7 mm and 5 mm respectively prior to placement of the UTFC.

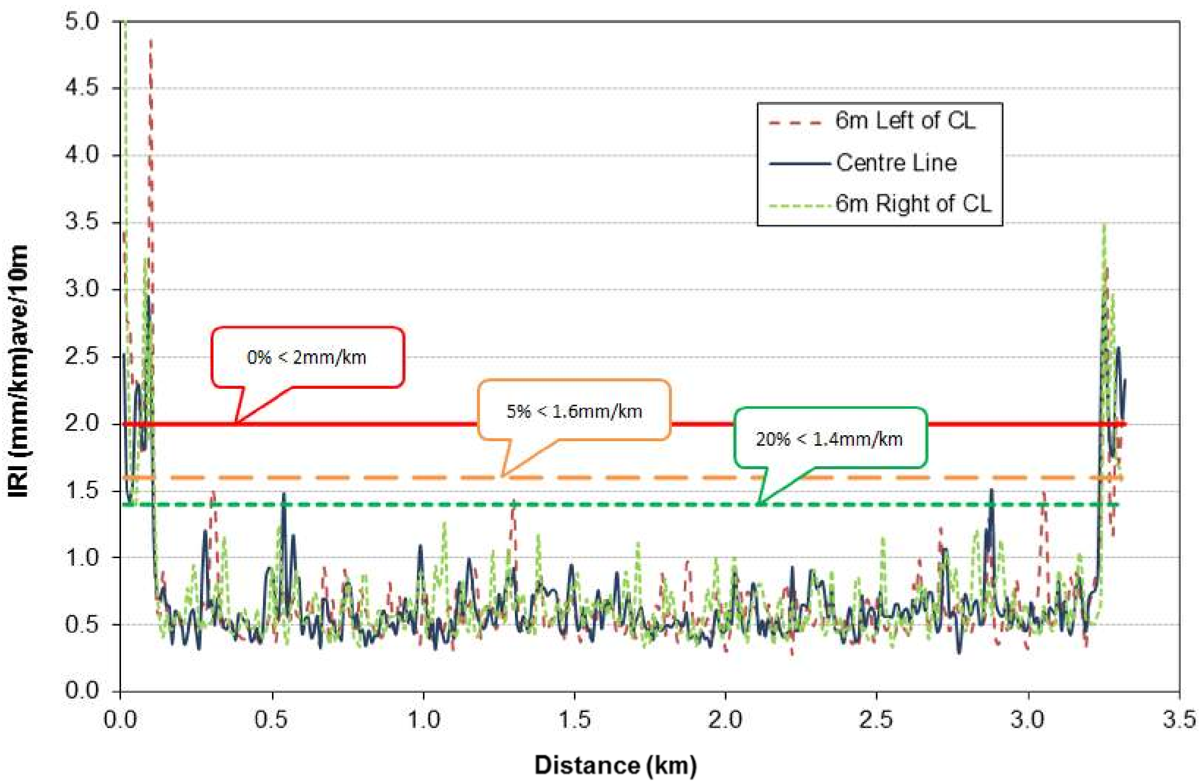

Figure 8: Runway 0119 IRI results

The start and finish readings in Figure 8 are ignored in each case due to the acceleration and deceleration at the end of the runway making such readings non representative. The criteria indicted are translated from the aforementioned FAA and ICAO criteria, which has the aim to prevent stormwater ponding from occurring on the runway.

6.3 Macro-texture and skid resistance

ICAO and FAA also provide guidance on macro texture and measured skid resistance. Newly constructed runways should comply with the following criteria:

(i) Grip-tester Grip Number (GN): >0.74 @ 65 km/h and >0.64 @ 95 km/h (1 mm waterfilm)

(ii) Texture depths: >1 mm

Figure 9 indicates sand patch measurements of the mean texture depth (MTD). Measurements achieved were in excess of 1.4 mm (average) over the central keel section of Runway 0119. The low results at the extremities were measured on the continuously graded AC applied to each turning pad in lieu of the UTFC, in order to provide increased transverse shear resistance under aggressive wheel movements associated with these areas of the runway.

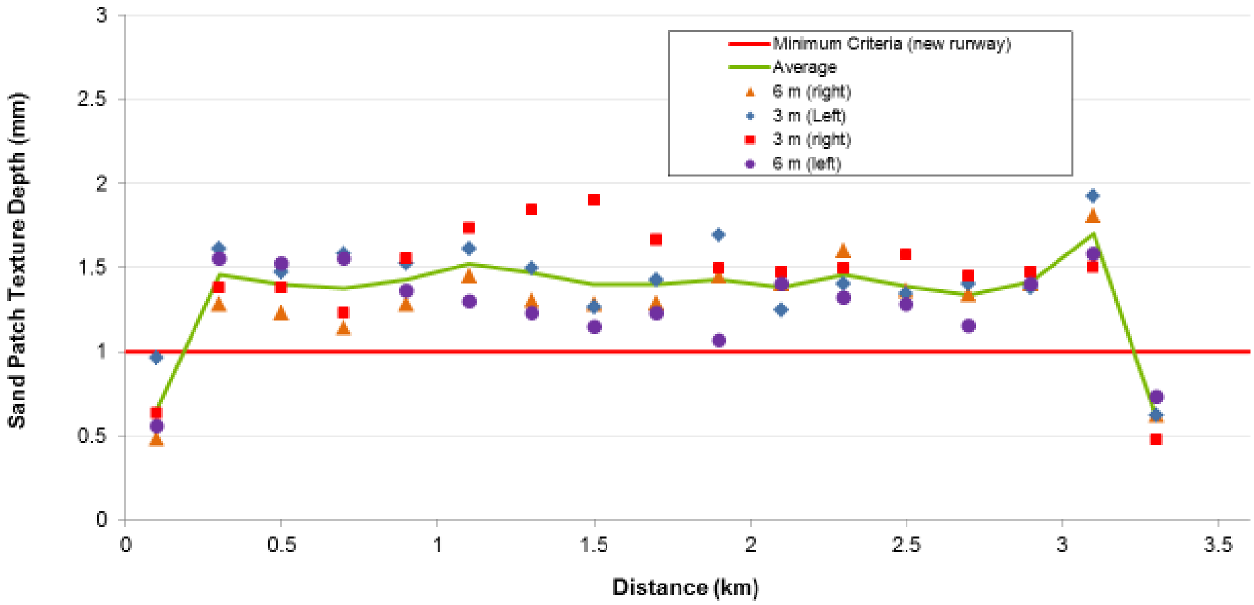

Figure 9: Runway 0119 sand patch texture depth measurements

Friction measurements were taken at both 65 km/h as well as 95 km/h with the Griptester is order to compute the GN. The GN can be defined as the braking force, measured as strain on the test wheel axle of the Griptester and is dependent on the skid resistance of the road surface. Only the 95 km/h GN-values are illustrated as they tend to better reflect the impact of both micro-texture and macro-texture on measured skid resistance (Horak et al, 2010). The existing secondary runway surface (continuously graded asphalt) was measured for comparative purposes. Figure 10 clearly shows that the UTFC surfacing on Runway 0119 provides GN-values above the ICAO specified criteria and while the secondary runway surfacing is below the values required for new construction, it plots above the maintenance limits specified.

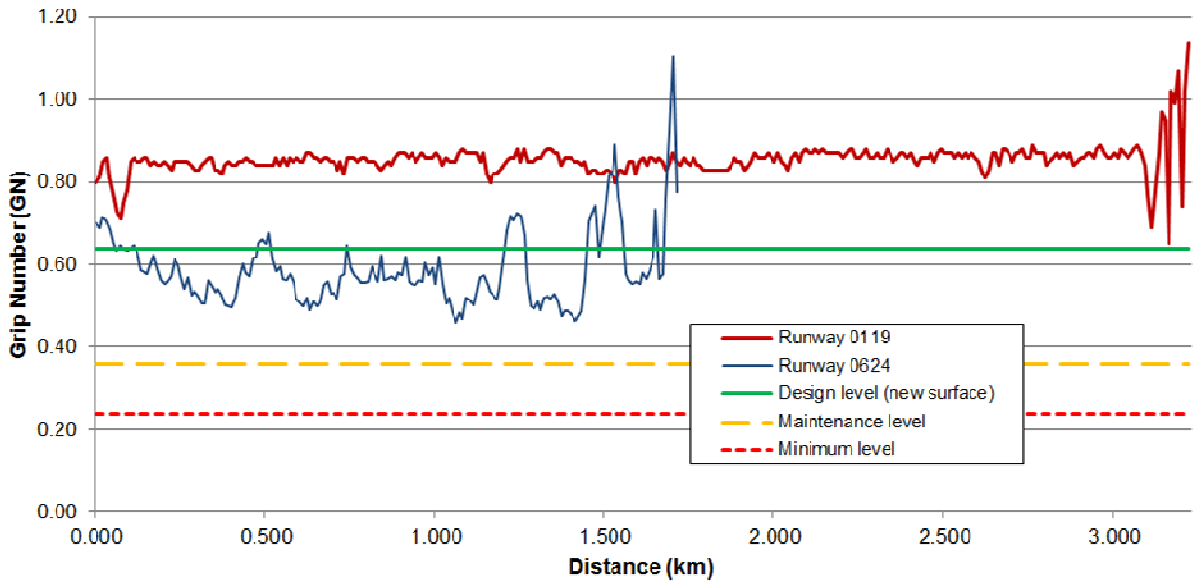

Figure 10: Runway 0119 Grip Number (GN)

Comparative results of similar proprietary product UTFC surfaces applied to runways in southern Africa were analysed to determine the performance of this surface with respect to skid resistance. Figure 11 compares the GN-values obtained on Runway 0119 at 95 km/h test speed with the GN-values measured at Bloemfontein and Upington at 65 km/h test speed. All three data sets were measured within 6 months of completion of construction.

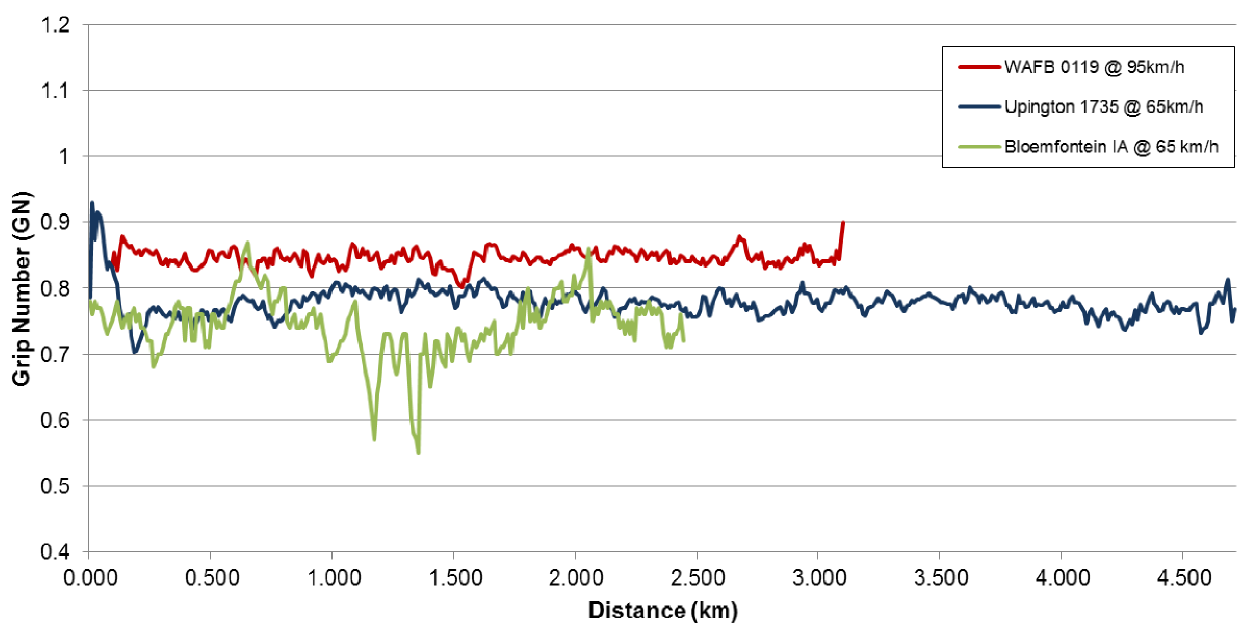

Figure 11: Comparison of GN measurements of UTFC surfacing applied to South African runways

The specific UTFC has been applied in South Africa and Namibia over the past 5 years. It is evident from the results that improvements have been made to the design and application of the UTFC since its initial application within southern Africa on Upington Airport and that the current design and application methodology ensures that the ICAO specification is met. The UTFC surfacing provides a highly competitive final surfacing compared to more traditional airport asphalt mixes, such as continuously graded mixes and stone mastic asphalt, which routinely require either water-jetting or grooving subsequent to construction to meet ICAO surface friction criteria for newly constructed runways.

7. RUNWAY UTFC FUNCTIONAL SPECIFICATION

Based on the results obtained on Runway 0119, as well as analysis of current and previous runway reconstructions, the following criteria for UTFC surfacings are proposed for surface friction applicable to airport runways. These criteria should be utilised in conjunction with the standard requirements and recommendations published by ICAO and FAA with respect to riding quality, texture and surface irregularities in order to ensure acceptable functional performance of newly constructed, reconstructed or overlaid runways

Table 4: Acceptance criteria for surface friction (UTFC surfacing)

Time (Years)	Limit Value - Grip Number		Maximum (%) of 100m Segment with GN Value Worse Than Limit Value
	65 km/h	95 km/h	
1	0.74	0.64	10%
	0.70	0.60	0%
2	0.74	0.64	10%
	0.70	0.60	0%
3	0.70	0.60	10%
	0.60	0.55	0%

8. CONCLUSION

Runway 0119 on Waterkloof Air Force Base (WAFB) is located on dolomite geological formations with high sinkhole risk classification. The runway is essential to accommodate the increasing VIP and traffic to the legislative capital, Pretoria, the increased humanitarian aid mission, airfreight and military freight and general military support activities by the South African Air Force.

The design challenge was to provide an operational runway for a 30-year deisgn period over sinkhole prone geotechnical conditions. The design philosophy incorporated a stormwater risk management system into the design.

The design objectives of Runway 0119 required that integrated dolomitic mitigation measures be implemented in conjunction with sinkhole protection within critical zones of the runway. This was achieved through extensive mass excavations, DC in combination with IC and the construction of 17,325 m^2 raft foundation under the runway landing zones. An extensive monitoring system was implemented as an early warning system of sinkhole formation through the application of precise leveling and strain gauges installed within the raft foundations.

Geometrically the runway was vertically realigned to comply to ICAO standards with specific attention being placed on ensuring that cross-fall was maintained at maximum allowable grade to improve stormwater drainage. Extended shoulders were added to increase the surfaced width to 75m which would provide the shortest drainage path to the cacthpit system.

The significant excavations (750,000 m^3), RAP and concrete created though the construction processes was optimally reutilised in the strengthened keel pavement design. Innovative use of slag in material in combination with mechanical modification improved the selected material by one to two material classes above the original design and provided a deep well-balanced pavement structure.

The pavement structure was designed with a strengthened keel to meet aircraft operations predicted over a 30-year design period. Both the bitumen treated base and asphalt layers were designed to ensure maximum fatigue cracking resistance while maintaining sufficient shear deformation resistance.

Functional performance testing of various UTFC runway surfaces constructed in southern Africa over the past 5 years was utilised to provide an improved design for application on Runway 0119. Criteria for surface friction are proposed for future application on airport runways.

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