Fast track planning and design and build of a new runway at Mthatha airport

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***Abstract*— Mthatha Airport was a small regional airport in a remote part of South Africa, close to the home of the late Nelson Mandela. It was expected to play a key role during Mandela's funeral, but the existing airside infrastructure was inadequate to cater for the international high visibility event. Authorities moved to improve the airside infrastructure as matter of national priority and urgency. This resulted in the fast track planning, design and build project of a new FAA group V/ICAO Code 4E runway at Mthatha airport. The upgrade had to be completed within 8 months, and before the funeral occurred. This paper describes the following technical aspects;**

- ***Planning the runway geometric layout and obstacle limitation surfaces.***
- ***Procurement of quality materials and innovative drainage provisions in a high rainfall region.***
- ***Pavement design using FAARFIELD, then adjusting to local materials and design norms using linear elastic models.***
- ***Adapt the fast track approach to the opportunities offered by materials and paving technologies available in this remote region.***
- ***Rapid stage construction solutions to enable emergency use of the airport by large aircraft in case the high visibility event occurred prematurely.***

This project was successfully completed within the short time limits and interim goals of possible emergency use. The technical challenges led to a number of innovative material and design utilizations in a logistical challenging remote rural area. The project was set within a fast tracked procurement process and shifting responsible client government implementing agencies.

Keywords: ***Fast –track, design-build, ultra-thin friction course (UTFC), bitumen stabilised material (BSM), jointed concrete pavement(JCP), apron, falling weight deflectometer, runway end safety area (RESA), drainage, environmental impact assessment, cement stabilized base and subbase (CSB and CSSB), FAARfield, stage construction, high visibility event (HVE), pavement classification number (PCN), Aircraft classification number (ACN).***

I. Introduction and Background

Mthatha Airport was a small regional airport serving Mthatha and the central regional district of the Eastern Cape Province in South Africa. The airport had a main runway with length 2000 metres and width 23 metres, and a disused grass secondary runway.

The anticipated funeral of Nelson Mandela prompted governmental inter-departmental planning and coordination for such an anticipated event which was a real possibility during 2011-2012. Mthatha Airport was the airport serving the district of Qunu, which is the home of Nelson Mandela, and this was expected to be his final destination. Mthatha Airport was therefore identified as a crucial logistic and transport hub for the anticipated influx of various international VIPs and Heads of State. The geographical position of Qunu and the Mthatha airport are indicated on the southern Africa map. The national main gateway, OR Tambo International Airport in Johannesburg would serve as the first port of call. The logistical analysis and planning found that Mthatha airport could only be used for 30 seater sized aircraft on a "drop and go" basis with limited apron capacity. The improvement of airside infrastructure capacity at Mthatha airport was therefore seen as of paramount importance.

Fig. 1. Mthatha Airport in the Eastern Cape Province of South Africa with inset identifying Qunu

II. Fast track contractual arrangements

The sensitive, but urgent nature of this work and its importance as a National Priority Project required very rapid execution. It was a condition of appointment by the client that the planning, design and construction of the works be undertaken in a "fast-track" manner in the shortest feasible period of time. Ndodana Consulting Engineers (Pty) Ltd (NCE) was appointed to design and execute the works. The preliminary and detailed design phases had to run concurrent with the actual execution of the works. Normal procurement procedures were adapted to fast track the process, and NCE had to form a joint venture with the contractor, Rumdel Cape Construction, for a Design Build procurement in line with normal FIDIC contract documentation.

The Eastern Cape Provincial Department of Transport further fast tracked the process by allowing the newly formed joint venture to use the recently tendered bill of quantities and rates based on an ongoing major roads contract in close vicinity basically as a supplement. Both parties to the Ndorum Joint Venture (NCE and Rumdel) were fortuitously involved on that roads contract for the client, Eastern Cape Provincial Department of Transport (DoT). This roads project was within 20km from the airport which further enabled fast establishment. Only inflation and escalation adjustment factors were applied to the very similar items of the roads contract rates tendered. The roads contract also had access to a hard rock quarry and an established crushing plant, which further short cut the long process of Environmental Impact Assessment (EIA) by at least six months.

The development plan and conceptual designs went through various scenarios, associated draft work packages and time frames during various interactions with senior role players from various government departments since mid-2011. The final scope of works identified in April/May 2012 were described as separate work packages to enable a phased completion, yet integrated final capacity improvement, over a short time period. It was a requirement that the existing airport should be kept fully operational during the construction period. The work packages thus identified are illustrated in the schematic plan in Fig. 2. The client varied through this period. The original implementing agency was the Eastern Cape Province DoT, and this changed to the South African National Department of Defense (SANDF) in May 2012, and then later the National Department of Transport (DoT) in October 2012.

III. Project Scope

The project scope was to provide a new 2720 x 45 m runway (parallel to the existing runway), with 7.5 m wide surfaced shoulders each side, 240 m Runway End Safety Areas (RESA), new link taxiways, a new apron and extensions to an existing apron, and new helipad. The design was done to ICAO Annex 14 design standards [1]. The design concept that had to be employed for the funeral regarding the forecast peak traffic was to use Mthatha Airport mainly as a drop and go aircraft logistic facility, with limited aircraft parking. The historic under provision and backlog of maintenance of the road network in the Eastern Cape Province forced an air logistics operation versus a road or rail option. Most of the VIP aircraft coming to Qunu would have had to be parked at other regional airports such as East London, Port Elizabeth and Bisho. These aircraft were deemed too large for the present Mthatha airport and included those aircraft expected to be used by various Heads of State. This included aircraft up to Boeing 747 and Airbus A330 and A340 in size. Other common VIP aircraft included the Boeing 737-700 (BBJ), and Falcon 900.Therefore the original arrangements implied smaller (30 seater) to hub and spoke from the other regional airports and drop and go at Mthatha airport. This capacity or through put restriction had to be improved in the short term as well as the medium term.

The project scope was to deliver facilities which could accommodate the funeral logistic requirements occurring at any time through the project obviously without prior notice. Protocol arrangements implied that there would only be a 10 day window for final clearance of any ongoing work before providing a functional runway during any stage of the planning, design and construction. This was tackled by first widening the existing runway so the aircraft type could be increased from a 30 seat to 100 seat capacity. This runway would eventually serve as the parallel taxiway once the new runway was completed. The existing runway as well as apron were also too close to the terminal buildings, etc. At the same time, work started on the foundations for the new runway which would increase the aircraft size capable to 300 seater capacity at least.

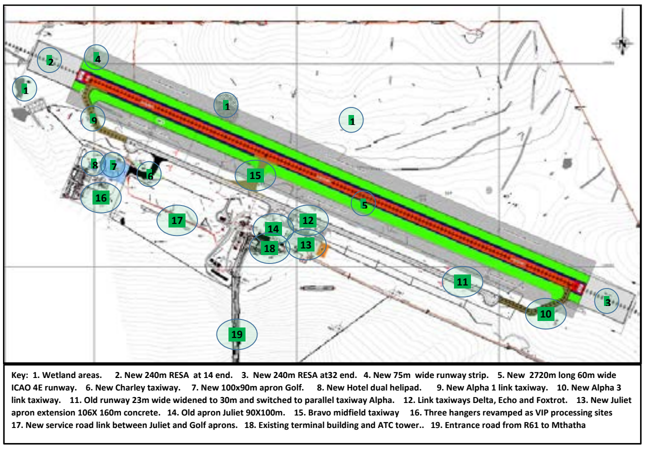


Fig. 2. Identification of work packages for Mthatha airport airside upgrade

The airport terminal rebuilding project, which was being handled by a standard separate building contract, experience prolonged contractual problems and finally contract termination early in 2012. This created an unforeseen scenario of a prolonged period of only limited passenger handling capacity with the temporary terminal facilities provided. A decision was made to refurbish the old airside hangers to function as VIP transit and processing areas. A haul road running parallel to the existing runway was urgently upgraded to link apron Juliet with the refurbished hangers in front of new apron Golf. Other minor work packages were also included to facilitate the logistic arrangements evolving.

VI. PHASED CONSTRUCTION APPROACH

A rapid phased construction approach maximized the capacity in as short a period as possible. In Table 1 the simplified phases of construction related to work packages are shown for various periods. The design of these work packages were to allow landing and takeoff in case of an event even during construction, but to have a functional Code C runway and to provide a fully functional Code E Runway to the airport over the eight months to cater for the anticipated high visibility event.

The widening of the existing runway was the easiest and quickest done by in situ milling and cement stabilization of the gravel shoulders. These strengthened shoulders were then provided with a bitumen slurry surface as blast protection runway shoulder width for engine protection up to ICAO Code C aircraft.

All the other phases shown had to be completed within eight months with ever increasing capacity improvements in that delivery period. Staged capacity improvements had to be done to provide a new basic 2.72 km runway in the first 5 months of construction and having the existing 2 km runway as either another Code C runway or a parallel taxiway in the final stages. Typically the additional apron Golf with taxiway Charlie were completed after month 5 which significantly improved the drop and go through-put potential. Acceleration of work was enhanced by having two shifts per day (10 hours per shift) totaling 20 hours. This was done to accommodate the still fully operational airport which was fortunately limited to daylight operations.

The health condition of Mandela fluctuated badly in December 2012 and led to the interim planning for the use of parts of the new runway under construction. A decision was made after month 5 to construct the keel area of the main runway first, with a crushed stone/bitumen emulsion mixture as the base course, and asphalt pave it with gravel shoulders for possible emergency use by military aircraft. This partially built runway (the keel was 22 m wide with compacted gravel shoulders) would be able to function in an emergency with the midfield link taxiway Bravo with a primed surface and only 50 mm thick asphalt surface as emergency access to the apron for the military aircraft. The end strips of the runway were constructed at full strength to provide turning circles for aircraft to taxi back to Bravo taxiway. This would have freed the old runway as fully functional for the drop and go activities envisaged with the improved capacity achieved linked to that old runway.

TABLE 1. PHASES OF CAPACITY IMPROVEMENT

Phase of capacity improvement	Months							
	1	2	3	4	5	6	7	8
Blast protection shoulders to existing runway for 30m surfaced width to act as Code C runway								
Extended Juliet apron and shaving of the hill to improve drop and go capacity and through put.								
Construct new apron Golf and taxiway Charlie to improve drop and go throughput								
Construct taxiways Foxtrot and golf for improved access and capacity on new enlarged apron Juliet and improve throughput capacity								
Construct keel area of main runway and taxiway Bravo with 50mm asphalt surfacing as emergency capacity improvement and end strips as temporary turning pads with partially completed RESAs								
Construct new runway 14-32 , link taxiways Alpha 1 and3 and switch existing runway to parallel taxiway and RESAs practical completion								
Completion of main runway UTFC and both RESAs to function as ICAO 4E or FAA code V airport								

Work continued on the new runway to widen it to the full 45 m width, plus surfaced shoulders out to 60 m wide in total. As various sections were completed, more logistic capability became available. The complete switchover of all flights from the old runway to the new runway could be done even before the link taxiways Alpha 1 and 3 were completed, as midfield taxiway Bravo was completed after month 6. The completion of link taxiways Alpha 1 and 3 at the end increased the capacity of the whole new runway significantly as small aircraft could use midfield taxiway Bravo without having to back track. Code C and larger aircraft could however back track as the whole last 200 m of both threshold areas had full strength pavement structures for the whole pavement surfaced width of 60 m for easy turnarounds. Temporary edge lights using low energy LED and solar light technologies were also installed over this period until the whole new runway base and asphalt surfacing were completed. The emergency intention was for military aircraft to be able to use the partially constructed new main runway in the case of the HVE before completion while other aircraft could use the old runway (now parallel taxiway Alpha) and thus provide capacity as well as protection for the VIPs.

VII. Geometric design Issues.

The undulating topography meant considerable fills of up to 9 m in height were required. The new parallel runway (14-32) was 45 m wide with surfaced 7.5 m wide shoulders to bring the total surfaced width to 60 m. The existing 23 m wide runway received 3.5 m wide shoulder hardening to give a total surfaced width of 30 m.

The new runway was off-set by 205 m north of the existing runway. This off-set distance was selected to ensure future possible upgrade or conversions to precision landing systems or upgrade to a 4F ICAO aerodrome class.

The airport boundaries had originally been set to accommodate a runway 3000 m in length without provision for runway end safety areas (RESAs). There were more restrictions imposed by environmental aspects, but the runway length had to be reduced to 2720 m to accommodate the runway end safety areas. The design aircraft included those expected to be used by various Heads of State, and included aircraft up to Boeing 747 and Airbus A330 size. The runway length to be provided should allow direct flights to neighbouring countries by all likely aircraft from those countries. It should allow even the largest aircraft to fly to Johannesburg, Durban or Cape Town and refuel there for further long haul or intercontinental flights. Given the airport elevation of 730 m above sea level, and the warm temperate climate with average monthly maximum air temperatures of 28.5 ^{0}C, the available 2720 m runway length was deemed acceptable.

ICAO 4E aerodromes require the runway to be located inside a 300 m wide runway strip (Fig. 2). The outer 75 m on both sides of the total runway strip functions as the fly-over strip, while the inner 75 m on both sides is a graded strip. On both runway ends, a surfaced 60 m end strip was provided then 240 m long runway end safety areas (RESAs) to meet the latest ICAO runway safety requirements.

VIII. Environmental Issues

The main activities of the upgrade project were restricted to the airport premises as shown in Fig. 2. The main focus of the environmental impact revolved around the impact on the wetlands on site. In Fig. 2 the wetland areas in the south eastern corner of the premises are indicated. The runway of 2720 m length was moved longitudinally with approximately 200 m away from the initial 14 end position eastwards to accommodate the wetland area in the western end of the premises. An independent wetland environmental expert was appointed to monitor the impact and condition of the wetland sections on the premises. This move of the runway came after one month of construction and caused additional fill requirements on the 32 end, particularly with the RESA area. There were a number of swampy areas towards the middle section which were identified as man-made, and permission was given to improve the drainage to prevent the unsafe situation of bird life attraction close to the airport.

IX. Drainage

The decision to use rock fill and a 600 mm pioneer layer throughout the runway length was validated within the first two months of construction. An abnormal high rainy season during the winter period added to the usual high water table levels, but this did not affect the work tempo, as excess water drained freely and the fill work could continue virtually unaffected. Construction vehicles could drive on this layer at all times. The shoulders were dedicated as haul roads. Various culverts were constructed at low points with precast culverts or precast concrete pipes linked into the existing drainage network. Excessive rains during and after the construction proved that all drainage was functioning very well. The rock-fill layer was covered with a geotextile sheet to prevent the selected subgrade layer from collapsing or filtering into the rock-fill porous areas.

X. Material sourcing and Mining Processing Issues

The initial design identified that considerable volumes of pioneered fill would be required for the pavement structural support layers and construction in wet weather. The identification of material sources was done at an early stage and in line with the environmental and mining permit requirements.

A. In Situ Materials along Alignment

The local geology map obtained from Geological Survey Services showed the majority of local material was either a mudstone or a sandstone. This was confirmed by geotechnical test pitting done up to 3 m deep along the proposed alignment of the new runway. The test pitting not only confirmed the material type to be correct, but also the presence of a thick overburden of sandy loamy soil with high water tables. It was estimated at an early stage that only approximately 30% of material from cut would be suitable for fill material and the rest suitable for landscaping and shaping requirements in the clearway or runway strip area.

Subsequent material testing of the in situ material on the center line identified subgrades with high plasticity index (PI) and with variable high swell potential. Therefore considerable under–cutting and use of rock fill or pioneer layers were planned and designed for to accommodate continuous construction at all times. Additionally high rock-fill (heights of 8-9 m) was needed to help curb the potential swell or settlement over time. Construction vehicles could also drive on the rock fill. Most of the material was machine removable except where the dolerite intrusions crossed the new alignment. Blasting was used and this decomposed dolerite material could also be used for rock-fill.

The grassed secondary runway was disused, and it still had a base and subbase layer of good quality natural gravel of CBR between 25 and 45. In the period preceding the obtaining of mining rights for the other sources of natural gravel, this material was literally recycled and used on the initial works such blending with rock-fill material to be used as a haul road and shoulder hardening of the existing runway. All of this enabled continuous construction activities.

B. Decomposed dolerite sources

Existing decomposed dolerite borrow–pits in relative close proximity to the airport were available, but were ignored due to the burden of rehabilitation and environmental requirements. Decomposed dolerite generally makes for good quality granular pavement construction, but secondary minerals and related durability issues may be a concern. A desk study and local plant identification process helped to identify a very favorable location of decomposed dolerite on site, which was confirmed by geological maps. Geotechnical test pitting proved up the borrow-pit area on both sides of the entrance road inside the airport premises. Initial tests confirmed that these potential borrow-pit sources would deliver good quality natural gravel material, possible to mine with machine excavation. Urgent application was thus made for the necessary mining license and as this was restricted to the airport premises the application process was shortened. Subsequent laboratory testing indicated that the natural gravel was in fact of a very good quality (soaked CBR values ranging between 25 and 80). The early laboratory results also showed that these materials would be ideal for good quality cement treated layers.

C. Hard Rock Requirements

Hard rock freshly crushed rock was required for concrete, base and asphalt surfacing work. Such material could be sourced from a commercial source east of Mthatha, but transport would have to go through the Mthatha built-up areas and business district. However the ongoing rural roads project mentioned before still had an operational quarry and was thus identified as most viable source for the crushed hard-rock requirements. The contractor still had a multi-stage crusher in place at this quarry. The mining license could be extended with minimum hassle. This quarry is approximately 32km from site by road, and the haulage had limited impact on the rural road system and traffic.

D. Rock-fill requirements

The previously mentioned new runway subgrade high swell and high PI values necessitated the use of a pioneer layer up to 600 mm thick, and rock fill layers elsewhere where undercutting or fills were to be done. A structural design decision was thus made to use rock-fill to overcome settlement on the high fills (up to 9 m) and to help speed up the considerable volume of fill construction under continuous construction with no settlement period needed for the fill. The RESA areas (240 m by 150 m wide) on both ends (14 and 32) made up large additional areas in need of such quality fill material, as both runway ends ended in fill due to sightline requirements from the low retained Air Traffic Control Tower.

The presence of an old un-rehabilitated hard rock quarry at Kambi Road just east of the 14 end of the runway was discovered by chance. This quarry had sandstone and baked shale with a dolerite dyke running through it. It appeared to have been used in the original construction of the airport, but the variability of the material observed in the high exposed vertical sides made this impractical for crushed fresh high quality rock material. However, the close proximity to the airport and the increased volumes of rock fill made this the ideal source for dump rock and rock fill source.

High level discussions with the Provincial Department of Mineral and Mining led to an agreement to follow the same parallel approach as agreed to for the environmental issues on the airport premises in the application for a mining license. The encroachment of the local community on the southern side meant that expansion with blasting could only be done towards the north. The normal mining application was followed and the ongoing monitoring and other process requirements were done in parallel to the actual mining taking place. No crushing was to be allowed which facilitated the fast tracking of the mining application. In the end a total 282 000 m^3 of rock-fill was used and 84 000 m^3 of pioneer layer.

XI. AIR TRAFFIC ANALYSIS

Mthatha historically had very low levels of passenger traffic using small aircraft, and this was forecast to grow modestly. More importantly, the airport had to be capable of handling air traffic associated with the Mandela funeral. This type of traffic could comprise Government aircraft, chartered aircraft of airliner size, and a multitude of media, NGO and private aircraft. Many nations maintain one or more special aircraft to transport their heads of state and government. Others charter appropriate aircraft.

The many aircraft types could be reasonably represented by a limited number of aircraft in the pavement design modelling. The many aircraft during the one-off peak event were modelled as few aircraft per year over the 20 years design period. In addition, normal airline growth and the possibility of larger aircraft using Mthatha airport were factored in, as well as the future co-use by military aircraft. In

Table 2 the peak traffic event and the other future scenarios were integrated over the 20 year design period to produce the traffic movements of the heavier aircraft to be considered in the pavement structural analyses.

TABLE 2. MTHATHA AIRPORT – AIRCRAFT DATA USED FOR PAVEMENT MODELING

Aircraft	MTOW (tonnes)	Annual departures	Annual growth rate (%)
A330-200	230.9	2	0
A340-200	257.9	1	0
737-700/BBJ	70.3	20	0
747-400	397.8	2	0
Falcon 900	20.6	50	0
C-130B	70.3	18	0
DH8-400 (Dual Whl-60)	28.4	104	2.4
J41 (Dual Whl-20)	10.9	654	2.4
PC-7 (Single Whl-5)	2.3	1000	0

XII. PAVEMENT STRUCTURAL AANALYSIS AND OPTIMIZATION

The traffic mix presented in Table 2 was used for design of all facilities. Flexible and rigid pavements were modelled using the FAARFIELD software, as described by Hayhoe [2]. Further validation and refinement of the candidate flexible designs were performed with the South African developed linear elastic Rubicon Toolbox pavement design and analysis software, facilitating evaluation of all layers in the flexible system and sensitivity to failure criteria used. This was necessary because South African and Australian practice is to use very thin layers of asphaltic concrete as the wearing course (50–60mm thick), which is a departure from the FAARFIELD assumptions. Such very thin asphalt only works successfully if the base course is of particularly high quality, as is discussed below. The following assumptions were made with respect to distribution of traffic on the new flexible runway pavement structure:

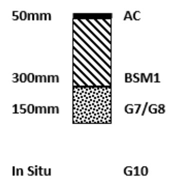
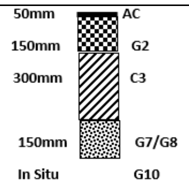
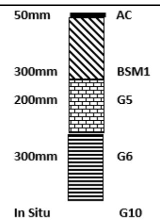
- The keel area (central 22 m) takes the full traffic spectrum (at least 95% of total)
- The off-keel area (off-set 11m to 22.5 m from centreline) only caters for 5% of the full traffic spectrum to cater for aircraft wander
- The 7.5 metre wide shoulder area will structurally cater for even less traffic than the off-keel area, without provision for a friction course.

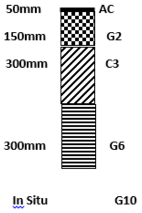
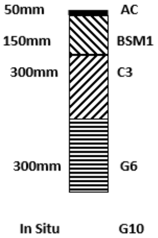
Various possible combinations of pavement layers were considered for the flexible pavement structures in order to ensure constructability, speed of construction and availability of materials before a final choice of pavement structures were made. In Table 3 the analyses for the two analysis approaches are shown. During the design phase, the strong possibility of very weak subgrades (as low as 3< CBR< 7) with possibility of swelling clay became apparent. As can be seen in Table 3 the options make provision for such weaker subgrade conditions.

The basecourse options included either a bitumen stabilized material (BSM) or a high quality freshly crushed stone base (G2). The BSM could use either asphalt bitumen emulsion or foamed bitumen to mix with crushed stone. The crushed stone is of a particularly high quality, and is deliberately built on top of a cemented layer to provide a semi-rigid platform for compaction, and is therefore able to be compacted itself to a minimum of 102% Mod. AASHTO.

The analysis included subbases of various thicknesses from 200 to 300 mm for granular material varying from fair (CBR>15) to good (CBR >45) quality as well as a 300 mm (12 in) thick cement modified material (UCS of 1.5 to 3 MPa) layer made from the same granular materials with a 3% cement addition. This sensitivity analysis was done with due consideration of the quality and availability of material on site. The 300 mm thick cement modified subbase option was reserved for the keel area. On the off-keel area a lower level cement modification (UCS 0.75 to 1.5 MPa) subbase was used and also reduced to 150 mm thick only on the shoulder where virtually no traffic occurs. These variations in material combinations are shown in Table 3.

TABLE 3. RUNWAY FLEXIBLE PAVEMENT DESIGN RESULTS

Pavement Structure Options (Layer thickness in mm, material type)		FAARFIELD life (years)	Rubicon Toolbox Life (years)
1		>>10	≈ 12
2		>>10	>>10
3		≈ 10	≈ 13

4		≈ 10	>>10
5		>>10	>>10

Legend: Material types as per SA Technical Recommendations for Highways TRH14 [3]. All CBR values in this paper are after 4 days soaking.
Synoptic TRH14 Material Description:
AC = Continuously graded asphaltic concrete;
G2 = 102% Mod AASHTO density freshly crushed stone continuously graded;
BSM1 = Bitumen Stabilized Material (BSM) achieved with crushed stone and quality natural gravel with 1% cement and typically 2% residual bitumen applied via emulsion or foamed process;
G5 = good natural gravel 45<CBR<80;
G6 = fair natural gravel 25<CBR<45;
G8 = poor natural gravel 7<CBR<15;
G10= very poor natural material 3<CBR<7; C3=Cement modified natural gravel to have unconfined compressive strength (UCS) between 1.5 and 3 MPa

In Table 3, the fourth structure [high quality crushed stone (G2) basecourse pavement structure shown in bold] was selected at the design stage. The worst case subgrade condition of a G10 material (3<CBR<7) is shown which necessitated an additional 500 mm rock fill pioneer layer. Where better in situ subgrade material quality was found this, pioneer layer was reduced to 300 mm. The rock fill was also given 5 metre wide drainage fins out to the sides enabling water flow out of the rock fill as an oversized fin-drain to accommodate drainage. This was done after the abnormal rain fall over the first few months and the observation of substantial quantities of ground water. These large fin drains were spaced at approximately 100 m intervals, and focused on the drainage at low points.

Around month 5 of the construction of the new runway had progressed to the completion of the cemented subbases. A rapid decline in the health of Mandela at that stage meant a need for additional acceleration to the construction. It was decided to construct the keel (inner 22 m) of the base with the more costly bitumen stabilized base (BSM) instead of a quality crushed stone base (G2) for that reason of speed of construction. This is the fifth structure in Table 3 and is shown in bold. The crushed stone base-course construction is known to be time consuming to construct, with good sunshine weather a requirement; both qualities which were in short supply at the time of construction.

The BSM designed in the laboratory was a 70% good quality crushed stone (G2) material mixed with a 30% fair-good natural gravel (G6: CBR >25 to G5 :CBR>45) material, which provided the needed fine material content, along with the addition of 1% cement. The off-keel areas structural designs were also changed to speed up construction. The G5/G6 quality decomposed dolerite material from the onsite decomposed dolerite borrow-pit provided excellent results with cement treatment and therefore the off-keel areas were constructed with a 150 mm (6 in) thick cement treated (C3) base-course layer instead of the planned high quality crushed stone (G2) base layer. The taxiway base layers were similarly changed from G2 to C3 layers. The material mix in these cases were 30% high quality crushed stone (G2) with 70% decomposed dolerite, and excellent UCS results were obtained with no signs of cracking.

The traffic mix presented in Table 2 was used for design of all facilities. Flexible and rigid pavements were modelled using the FAARFIELD software, as described by Hayhoe [2]. Further validation and refinement of the candidate flexible designs were performed with the South African developed linear elastic Rubicon Toolbox pavement design and analysis software, facilitating evaluation of all layers in the flexible system and sensitivity to failure criteria used. This was necessary because South African and Australian practice is to use very thin layers of asphaltic concrete as the wearing course (50–60mm thick), which is a departure from the FAARFIELD assumptions. Such very thin asphalt only works successfully if the base course is of particularly high quality, as is discussed below. The following assumptions were made with respect to distribution of traffic on the new flexible runway pavement structure:

- The keel area (central 22 m) takes the full traffic spectrum (at least 95% of total)
- The off-keel area (off-set 11m to 22.5 m from centreline) only caters for 5% of the full traffic spectrum to cater for aircraft wander
- The 7.5 m wide shoulder area will structurally cater for even less traffic than the off-keel area, without provision for a friction course.

Various possible combinations of pavement layers were considered for the flexible pavement structures in order to ensure constructability, speed of construction and availability of materials before a final choice of pavement structures were made. In Table 3 the analyses for the two analysis approaches are shown. During the design phase, the strong possibility of very weak subgrades (as low as 3< CBR< 7) with possibility of swelling clay became apparent. As can be seen in Table 3 the options make provision for such weaker subgrade conditions.

The base course options included either a bitumen stabilized material (BSM) or a high quality freshly crushed stone base (G2). The BSM could use either asphalt bitumen emulsion or foamed bitumen to mix with crushed stone. The crushed stone is of a particularly high quality, and is deliberately built on top of a cemented layer to provide a semi-rigid platform for compaction, and is therefore able to be compacted itself to a minimum of 102% Mod. AASHTO.

The analysis included subbases of various thicknesses from 200 to 300 mm for granular material varying from fair (CBR>15) to good (CBR >45) quality as well as a 300 mm (12 in) thick cement modified material (UCS of 1.5 to 3 MPa) layer made from the same granular materials with a 3% cement addition. This sensitivity analysis was done with due consideration of the quality and availability of material on site. The 300 mm thick cement modified subbase option was reserved for the keel area. On the off-keel area a lower level cement modification (UCS 0.75 to 1.5 MPa) subbase was used and also reduced to 150 mm thick only on the shoulder where virtually no traffic occurs. These variations in material combinations are shown in Table 3.

In Table 3, the fourth structure [high quality crushed stone (G2) basecourse pavement structure shown in bold] was selected at the design stage. The worst case subgrade condition of a G10 material (3<CBR<7) is shown which necessitated an additional 500 mm rock fill pioneer layer. Where better in situ subgrade material quality was found this, pioneer layer was reduced to 300 mm. The rock fill was also given 5 m wide drainage fins out to the sides enabling water flow out of the rock fill as an oversized fin-drain to accommodate drainage. This was done after the abnormal rain fall over the first few months and the observation of substantial quantities of ground water. These large fin drains were spaced at approximately 100 m intervals, and focused on the drainage at low points.

Around month 5 of the construction of the new runway had progressed to the completion of the cemented subbases. A rapid decline in the health of Mandela at that stage meant a need for additional acceleration to the construction. It was decided to construct the keel (inner 22 m) of the base with the more costly bitumen stabilized base (BSM) instead of a quality crushed stone base (G2) for that reason of speed of construction. This is the fifth structure in Table 3 and is shown in bold. The crushed stone base-course construction is known to be time consuming to construct, with good sunshine weather a requirement; both qualities which were in short supply at the time of construction.

The BSM designed in the laboratory was a 70% good quality crushed stone (G2) material mixed with a 30% fair-good natural gravel (G6: CBR >25 to G5 :CBR>45) material, which provided the needed fine material content, along with the addition of 1% cement. The off-keel areas structural designs were also changed to speed up construction. The G5/G6 quality decomposed dolerite material from the onsite decomposed dolerite borrow-pit provided excellent results with cement treatment and therefore the off-keel areas were constructed with a 150 mm (6 in) thick cement treated (C3) base-course layer instead of the planned high quality crushed stone (G2) base layer. The taxiway base layers were similarly changed from G2 to C3 layers. The material mix in these cases were 30% high quality crushed stone (G2) with 70% decomposed dolerite, and excellent UCS results were obtained with no signs of cracking.

XIII. Performance Evaluation of the New Runway Pavement Structure

The new runway was tested with a Falling Weight Deflectometer (FWD) traverse at a 100kN and a 120kN drop weight giving respectively 1415kPa and 1700kPa drop contact stress. The FWD deflection bowl parameters were then used in a relative benchmarking methodology. The survey was done at 20m length intervals and traverses at 6m spacings starting 3metre left or right from the centre line. This assesses the relative structural condition of the pavement, across its length, breadth and depth. The benchmark or comparative structural condition evaluation uses a simplified three level system of condition rating on isographs or graphs to identify the various layers and areas of various structural conditions, as reported by Horak and Emery [4].

In Fig. 3, the benchmark analyses are shown determined by means of traverses left and right from the centre line at 3 m, 9 m, 15 m and 21 m. The relative structural condition or strength of the base layer, the subbase and the selected and subgrade layers can be determined by various simple deflection bowl parameters with self- explanatory names. The base layer index (BLI- which is the difference between deflection at the 0 and 305 mm geophones), middle layer index (MLI- which is the difference between deflection at 305 mm and 610 mm geophones) and lower layer index (LLI - which is the difference between the deflection at 610 and 915 mm geophones).

From this Fig. 3 it can be seen that the subgrade and selected lower layers (as per LLI graph) were well within the sound condition. This is testimony of the structural contribution of the rockfill and pioneer layer used throughout. The subbase layer showed only warning spikes on the outer edges of the runway shoulder at 21metre from centerline (as per the MLI benchmark graph). The inner keel area subbase layer was in the sound condition though. The base and surfacing combination layer showed a sound structural condition except for the off-keel outer edges of the shoulder (21metre from the centre line) where it spiked a few times into a marginal warning condition. All in all this benchmarking showed that the pavement structure is, as designed, structurally sound.

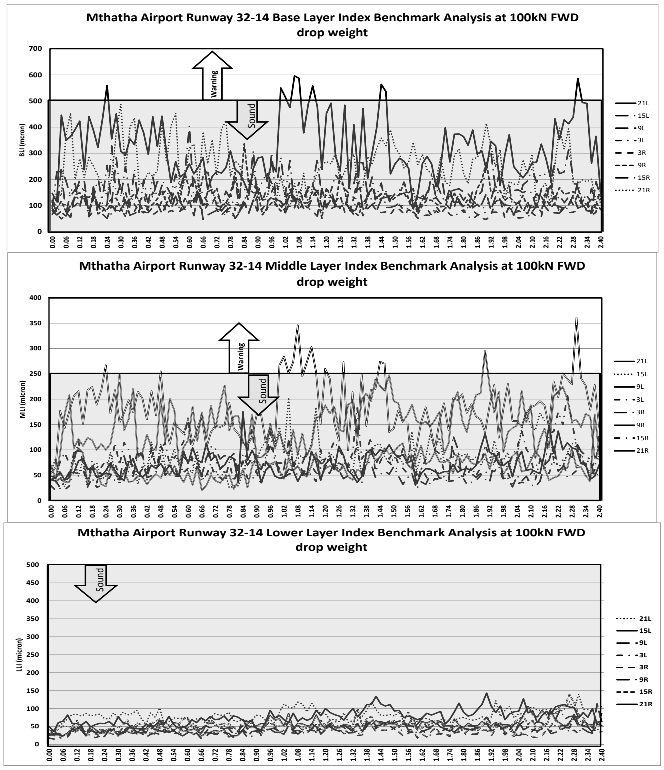


Fig. 3. Benchmark Analysis with Deflection Bowl Parameters of Runway

PCN calculation from FWD surface deflections was facilitated using the Dynatest ELMOD software. The Boeing 747-400 was used as the design aircraft. Using this data set, the 10th percentile PCN statistic was used as an indicator of potential pavement strength whilst the final maximum PCN is limited to 10% above the ACN for the subgrade under consideration. For classification purposes, the characteristic subgrade strength was based on the 10th percentile back-calculated subgrade modulus. The PCN was set as 65/F/A/W/T, substantiating the observation based on the benchmark analysis above.

XIV. CONCLUSIONS

The Mthatha airport airside was upgraded in a fast track design build project to facilitate the logistical arrangements associated with the anticipated funeral arrangements of Nelson Mandela. The project started May 2012 and was completed well before the actual funeral December 2013. The capacity of the airside infrastructure was improved in three stages over 8 months. The short term and immediate capacity improvement focused on hardening the outer 3.5 m shoulders of the existing runway to accommodate 100 seater aircraft. Interim improvement was achieved by enlarging the existing apron as well as building a new apron within the first 5 months. The final full capacity improvement was provided by the completion of the new 2720 m length runway parallel to the existing runway, within the 8 months contract period.

The following innovative and emergency design and implementation procedures contributed to the success of the project:

- Conversion to a design build project and using an existing large roads project as basis to include the competent contractor in a joint venture with the consultant.
- Making use of an existing hard rock quarry linked to the previously mentioned roads contract in close vicinity to provide quality crushed rock material. Fast track mining license and environmental impact assessment procedures to use an existing nearby un-rehabilitated Kambi quarry as rock fill and pioneer material.
- Finding and utilizing a good source of decomposed dolerite material on site which limited environmental impact issues providing for most of the granular layer requirements.
- Mitigating effects of high PI and swell potential of the subgrade by using blasted rock as rock fill and as pioneer layer. No work was halted due to excessive un-seasonally rains as the rock fill facilitated good drainage of the structure.
- Environmental impact assessment was restricted to the airport premises and allowed to run its course of application in parallel to the actual work done.

Acceleration of the work was achieved by:

- Rapid construction methodologies and working extended hours of two shifts of 10 hours while the existing runway was kept operational during the day and night.
- Various pavement options were identified that enabled a switch from crushed stone base to an bitumen emulsion treated base for the keel area to speed up the construction process and provide for interim emergency facilities for military aircraft.
- Constructing the off-keel area and shoulders with a mechanically modified decomposed dolerite cement stabilized base and subbase enabling considerable acceleration of the runway construction and not influenced by excessive rains.
- Geotextiles were used to protect filtering into the rock-fill and large fin drains with geotextiles and rock-fill fed water directly at rock fill level out of the fills even during construction.

From measured deflections, structural benchmark analyses of the completed runway showed that the subgrade and selected layers were remarkably strong overall due to the rock fill and pioneer subgrade improvements while the rest of the pavement structure was structurally sound. PCN calculations substantiated adequacy of the runway to accommodate the Boeing 747-400 design aircraft.

The project was completed in a situation of changing of the implementing client which contributed to uncertainty regarding payment issues, increased scope of work and yet increased emergency actions during the actual rapid design build process due to the fluctuating health condition of Nelson Mandela. Madiba’s funeral took place in December 2013 with no problems associated with the planned logistical provisions made.

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