INNOVATION IN OVERCOMING ROAD REHABILITATION CHALLENGES FACED IN AN URBAN ENVIRONMENT: AN IN-DEPTH CASE STUDY

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ABSTRACT

The design and implementation of a pavement rehabilitation project in a Central Business District (CBD) of a city poses numerous challenges. These challenges include the high design traffic, depth of pavement rehabilitation, presence of many services, traffic accommodation, pedestrian accommodation, construction period, construction materials, final level of construction, environmental and social impact and sustainability.

The paper presents a case study of an innovative pavement design and construction process for the rehabilitation of Harvey Road and Hanger Street in Bloemfontein, South Africa. The paper addresses the practical rehabilitation option, which met the challenges faced on the project, as well as the construction materials mix design details, construction methods, time frames during construction as well as a cost comparison between conventional deep rehabilitation pavements and the innovative rehabilitation pavement. The design incorporates a bitumen emulsion stabilised crushed stone base, which includes reclaimed asphalt, paved with a paver on top of a mechanical stabilising grid.

1 INTRODUCTION

Royal HaskoningDHV (RHDHV) was appointed by the Mangaung Metro Municipality (MMM) in 2011 for the rehabilitation design of Harvey Road and Hanger Street in the CBD of Bloemfontein, South Africa.

Harvey Road and Hanger Street form an important bus and taxi route serving the Intermodal facilities, linking taxis, busses and rail. The roads also serve as link roads for the travelling public between two major arterials in Bloemfontein, ultimately connecting the N1, N6 and N8 National roads.

The two respective roads' sections showed different types of distress, which include crocodile cracking, deformation, longitudinal cracking, transverse cracking, degraded patches, potholes and undulations.

The design and implementation of the rehabilitation action on the two roads posed numerous challenges. These challenges include inter alia the high design traffic, depth of pavement rehabilitation, presence of many services, traffic accommodation, pedestrian accommodation, construction period, construction materials, environmental and social impact and sustainability.

This paper presents an in-depth case study of an innovative pavement design and construction process for the rehabilitation of Harvey Road and Hanger Street. The paper addresses the practical rehabilitation option, which met the challenges faced on the project, as well as the construction materials mix design details, construction methods and time frames, as well as a cost comparison between conventional deep rehabilitation pavements and the innovative rehabilitation pavement. The paper is a succession on a paper presented at the 6th Africa Transportation Technology Transfer (T^2) Conference in Botswana in March 2013.

The innovative rehabilitation design consists of milling out the existing surfacing plus base and paving a bitumen emulsion stabilised crushed stone base, which includes reclaimed asphalt, on top of a mechanical stabilizing grid. The bitumen emulsion stabilised material was mixed off-site by using a pug mill, which was specifically designed for this project and can be used for similar projects or pre-coating of aggregate for sealing applications.

2 THE DESIGN CHALLENGES AND MITIGATION

Numerous challenges were faced on the project. The design had to overcome these challenges and the final rehabilitation solution made this design innovative. The challenges and mitigation factors were as follow:

2.1 High design traffic

The aim of the design was to design a pavement that has a 20 year design life and caters for a design traffic class of E3 (according to the UTG3, 3-12 Million Equivalent 80 KN axles) for Harvey Road and E4 (12-50 Million Equivalent 80 KN axles) for Hanger Street. The high design traffic demands a strong and deep pavement structure.

2.2 Inadequate lower layers of the pavement

The centerline investigation at the various sections revealed varying materials with regard to quality and thickness. This variability indicates that the sections were constructed independently and manifests different distress characteristics. The materials present in the lower layers of the existing pavement were not providing the necessary support for the future design traffic, which means that the material with a low bearing capacity (low CBR material), need to be replaced by better quality material.

In a nutshell, the existing pavement consisted of the following:

- Poor or insufficient quality of selected and subgrade layers. Selected layers on some sections consisted of G10 material.

- High degree of variation in the quality of the selected and subgrade layers of the different sections.
- Occurrence of large packed stones (250 mm – 300 mm), like a Macadam pavement, below the surface on some sections. Harvey road is serving the railway station, which dates back to the early 1900's as the railway line from Bloemfontein to Colesberg was completed in 1890. The type of Macadam pavement in sections of Harvey Road and Hanger Street most probably dates back to the early 1900's.

2.3 Abundance of services

Services e.g. electric cables, telecommunication cables, water pipes etc. as shown in Figure **1** are located in the lower layers of the existing pavement structure and ascertained the depth of rehabilitation. A very old lead based water pipeline resided on some sections and embarking on this service would be detrimental to the project, because fittings and or couplings for this old service were unobtainable. The cost to replace the whole service would outweigh the cost of the whole project, thus it was not an option to do deep rehabilitation.

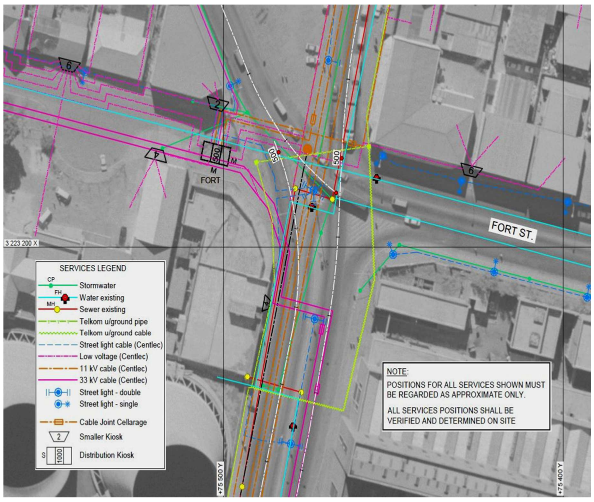

Figure 1: Layout of services at the intersection of Harvey Road, Hanger Street and Fort Street.

Figure 2: Pedestrians in Hanger Street.

2.4 Construction level fixed

The final level of the rehabilitation was fixed between the existing kerbs, thus the rehabilitation action excluded the option of adding layers on top.

2.5 Pedestrian, traffic and logistics in the city

The roads are located in the CBD and serve the intermodal facility linking buses, taxis and rail. The pedestrians and traffic accommodation was a major challenge and a huge contributing factor to the rehabilitation design and construction method. Shallow excavation would allow pedestrians to cross over the excavation and it would lower the risk for serious accidents, due to deep excavations, for the travelling public. Figure 2 represents a picture taken of the pedestrians in Hanger Street in the afternoon before peak hour.

Traffic consists of buses, taxis, cars and heavy vehicles or delivery vehicles travelling through the city. Lane and intersection closures would create widespread congestion and would close off accesses to the numerous shops and buildings, which required a fast and easy rehabilitation action. Congestion also causes indirect cost to the road user and because these roads serve public transport vehicles, it was crucial that the construction actions and construction period was limited as much as possible.

2.6 Preferred construction materials and in-situ materials

The existing base material consisted of G5 material, which would not suffice as a base material for such a high design traffic. The TG2 guideline also denotes that design traffic of higher than 3 million E80s demands a better quality base material e.g. crushed stone.

Availability of G3 and G2 material from commercial sources in Bloemfontein is limited, while G1 material are generally available.

Mechanistic pavement design analysis calculated that a G1 material on top of the existing subbase of G5 quality, in combination with the inadequate selected and sub-grade layers, would not carry the design traffic.

Emulsion stabilized crushed stone (G1/G2) material, in combination with the existing selected and sub-grade layers would be able to carry the design traffic, but this would require a base thickness beyond 300 mm. The allowable rehabilitation thickness envelope was 150 mm to 200 mm on the respective roads. This thickness limitation on the rehabilitation of the base, led to the design of the pavement structure, which include the mechanical stabilizing grid.

The design is also environmental friendly in materials usage. Very little of the existing in-situ material is spoiled. The existing asphalt is re-used as reclaimed asphalt in the emulsion stabilised crushed stone mix and the existing base material is re-used as base material during the construction of the pedestrian walk ways. The rest of the base material was stockpiled for future use by the municipality for other projects and road maintenance. No subbase or selected layers needed to be replaced in this case, which was also a saving of material sources and no spoiling.

2.7 Construction method with the least impact on the environment

The rehabilitation construction method had to be fast and easy, limiting hazardous and unfriendly conditions created by construction traffic for pedestrians, traffic, inhabitants of the city and surrounding buildings.

Excavation/milling depth was shallow (190 mm to 240 mm), which made the construction site safer for pedestrians and traffic. Less dust was present during the milling operation and no dust was present during the paving operation. Both milling and paving operations were fast, which resulted in shorter periods that pedestrians and traffic were exposed to construction activities.

The emulsion stabilised crushed stone could be paved with a paver, which resulted in a pedestrian and traffic friendly construction method, because less construction plant were needed, which could in fact caused accidents. The paving mix was mixed off-site at the pug mill plant and delivered with tipper trucks to the paver – similar as in asphalt paving, with the exception that the mix was paved cold. A cold mix also allows for less hazardous conditions for labourers and pedestrians. The conventional construction method of crushed stone involves working with a grader, slushing with a water cart, using brooms and creating dust, which poses an environmental hazard in a city centre.

Observations made on site proofed that traffic (including heavy vehicles), could be diverted onto the paved base within 3 hours after construction. Intersections and turning areas were slushed with diluted emulsion to produce a smoother surface for the prevention of aggregate loss under the turning movements of the vehicles' tyres. However, care should be taken to open the newly paved section to traffic in rainy conditions, as too much water on the base can damage it under the action of vehicle tyres driving over it. The damage base cannot easily be repaired and repairing it include the laying of a thicker asphalt surfacing to obtain the final levels. Final construction levels were more accurate by using a paver to pave the base.

The paving of emulsion stabilised crushed stone, which is pre-mixed at the pug mill plant is constructed much easier in confined areas or short lengths of construction, than conventional crushed stone. Conventional crushed stone construction is not as easy in confined areas or short sections, due to the working of the material by graders, brooms, water carts, etc. especially in a city environment, where turning movements are limited.

2.8 Low strength selected and subgrade layers and pavement strength balance

The low strength selected and subgrade layers and the pavement strength balance was a challenge for the designers. To compensate for the low bearing strength and variability, various stabilising grids were investigated. In conclusion, the mechanical stabilising grid from Tensar was the final choice for this project. The required thickness of the base could be reduced to 150 mm and 200 mm respectively, by installing the mechanical stabilising grid. The mechanical stabilising grid used on this project was Tensar Triax Tx170 (Figure 3), supplied by Kaytech Engineered Fabrics who is the distributor in South Africa for Tensar products. The reader can refer to the product supplier for the properties and characteristics of the products used on this project.

Figure 3: Rolled out Triax TX170.

In essence, the mechanical stabilising grids are increasing the bearing capacity of the lower weak and variable layers, leading to a reduced layer thickness of the top layers.

The initial pavement design, excluding the stabilising grid, was confirmed using the Pavement Number Structural Design Method described in the TG2 guideline. The pavement design, including the stabilising grid, was refined by using TensarPave Design Program software by Tensar International Limited.

Usually it is prescribed not to drive directly on the mechanical stabilised grid, but in this scenario, the paver was driving directly onto the grid, which made this project unique and innovative. Initially a paver with tracks was specified, but during the trial section, it was concluded that a paver with wheels could be used. However, care should be taken not to make turning movements onto the grid. Each 50 m grid roll was rolled out and paved upon, before rolling out the next section of grid, in order to prevent too much construction traffic driving onto the grid.

3 INNOVATIVE PAVEMENT DESIGN STRUCTURE

The aim of the design was to find a practical, customized and uniform solution for each road. The rehabilitation pavement structure includes the milling out of the existing surfacing and base, rolling out the mechanical stabilizing grid and paving an emulsion stabilised crushed stone on top of the mechanical stabilizing grid. The surface consisted of 40 mm asphalt. Table 1 represents the different pavement structures for Harvey Road and Hanger Street, based on the different design life of the respective roads.

Table 1: Innovative Pavement Structure.

Harvey Road		Design Life
Mill out Asphalt	40 mm Asphalt	8 Million E80s
Mill out ±150 mm existing base	150 mm bitumen emulsion stabilised material including the reclaimed asphalt	
	Mechanical stabilizing grid	
Existing pavement subbase and selected material layers		
Hanger Street		
Mill out Asphalt	40 mm Asphalt	18 Million E80s
Mill out ±200 mm existing base	200 mm bitumen emulsion stabilised material including the reclaimed asphalt	
	Mechanical stabilizing grid	
Existing pavement subbase and selected material layers		

*E80 = Equivalent 80 kN axles

4 CONSTRUCTION ACTION, TIMEFRAME AND ASPECTS

4.1 Milling of existing asphalt and base

The milling out of in-situ asphalt on straight, long and wide sections took on average one hour. The milled out asphalt was screened through a 32.5 mm sieve to remove large material chunks as required by the grading envelope and stockpiled for use as reclaimed asphalt as part of the new base material.

The milling operation of the base (Figure 4) took on average 4 hours. The finishing and cleaning (±4 hours) operation of the milled sections was carried out through the day (±4 hours), and the base was paved (Figure 5) during the evening and early morning hours.

Figure 4: Milling out of existing base.

Figure 5: Paving of base.

4.2 New bitumen emulsion stabilised base

The new emulsion stabilised base, conformed to a BSM1 (bitumen stabilised material) standard, according to the TG2 guideline. It consisted of virgin aggregate material, namely G1 crushed stone material, obtained from commercial sources.

The mix consisted out of the following:

- 75 per cent G1, natural crushed stone;
- 25 per cent reclaimed asphalt (RA);
- 2.5 per cent netto bitumen (SS60 emulsion);
- 1.2 per cent cement (CEM II B-L 32.5 N – as was available in the area), and
- 2 300 kg/m^3 average max dry density.

The specification of a BSM1, according to a level 2 mix design has an average maximum dry density of 2 300 kg/m^3 and conforms to an ITS dry, 100 mm diameter specimen of minimum 225 kPa and ITS wet, 100 mm diameter specimen of minimum 100 kPa. The Unconfined Compressive Strength (UCS) of the mix was between 1 200 kPa and 3 500 kPa.

4.2.1 In-plant Pug Mill mixing of the base material

The contractor used a custom built pug mill (Figure 6), based at a site plant, for the production of the bitumen stabilised material. The pug mill was built inside a marine container and can be folded into the container for easy transportation and quick de-establishment.

Figure 6: Pug mill at site plant.

The normal production rate was 70 t/hr and can be adjusted from 30 t/hr to 100 t/hr. The maximum dry density of the mix is on average 2.3 t/m^3, thus an average batch for a 150 m long section, 3.8 m wide and 200 mm deep, can be prepared in 2 hours. The mixed base material was stockpiled before loading onto tipper trucks for delivery to the paver.

4.3 Paving of the BSM material

The base was paved (Figure 5) in half a day using a normal asphalt paver and rolled immediately with a smooth drum vibratory drum roller, followed by a three point steel drum roller (Figure 8) and then a pneumatic roller. It has been observe that the material easily segregates if it is on the course side of the envelope and care should be taken not to keep the augers of the paver running too long, while the paver is stationary and waiting for the next delivery truck to hook on. The combination of the rollers and rolling effort is important to achieve a perfect surface and MOD AASHTO density. The density as specified for the *base* layer was 100 % MOD AASHTO for the average of the test section and not less than 98 % of MOD AASHTO density for a single test.

The final layer (Figure 7) density was tested by using a nuclear device.

Figure 8: Rolling the base.

Figure 7: Finished base.

5 COST COMPARISON BETWEEN THE INNOVATIVE DESIGN AND A CONVENTIONAL DEEP PAVEMENT DESIGN

The cost of the bitumen and stabilisation grid design was compared with a conventional deep pavement rehabilitation design. A typical section length of 150 m by 3.8 m wide was used to do the cost analysis. The actions included in Table 2 include the construction activities and the estimated time related costs. The normal pavement activities are listed as well as their estimate duration. The repair and replace of services are the factors that can drastically alter the final project value. The rate of R2.36 for fixing/replacing/protection of services in the bitumen emulsion stabilised pavement is derived from the actual expenditure on the project, which was R50 000 (ZAR) spent on the 21180 m^2 area. The rate of R94.43 in the conventional pavement, was derived from an estimated cost of R2 000 000.00 (ZAR) for the 21180 m^2 area, which is a cost estimate of 10 per cent of the total value of the project.

Table 2: Cost comparison.

DESCRIPTION	UNIT	QTY	RATE	AMOUNT (ZAR)	TIME (day)
Bitumen Emulsion Stabilised Pavement: 150 mm BSM, Mechanical Stabilising grid					
Mill out asphalt	m^3	22.8	448.00	R 10,214.40	0.5
Mill base	m^3	85.5	187.00	R 15,988.50	0.5
Placing of mechanical stabilising layer	m^2	570.0	63.00	R 35,910.00	
Paving of Emulsion stabilised base	m^3	85.5	875.00	R 74,812.50	
Emulsion in stabilized base	l	8550.0	8.64	R 73,872.15	1
Cement in stabilized base	ton	2.0	1,600.00	R 3,146.40	
Surface enriching layer	m^2	570.0	13.00	R 7,410.00	
Curing of layer					7
Prime	l	427.5	11.20	R 4,788.00	1
Tack	l	313.5	5.00	R 1,567.50	0.5
Asphalt	ton	54.7	1,667.00	R 91,218.24	
SUB-TOTAL				**R 318,927.69**	
Fixing/replacing/protection of services	m^2	570.0	2.36	R 1,345.61	2
Time related costs	Month	0.6	132,057.00	R 75,032.39	
SUB-TOTAL				**R 76,378.00**	
			TOTAL	**R 395,305.68**	**12.5**
Conventional Deep Pavement: 40 AC, 150 G1, 200 C4, 150 G7, 150 G9 (TRH4 design)					
Mill out asphalt	m^3	22.8	448.00	R 10,214.40	0.5
Mill base	m^3	85.5	188.00	R 16,074.00	1
Mill subbase	m^3	85.5	291.00	R 24,880.50	1
Mill/excavate selected layers	m^3	85.5	161.00	R 13,765.50	3
Mill/excavate selected layers	m^3	85.5	161.00	R 13,765.50	3
Roadbed preparation	m^3	85.5	25.00	R 2,137.50	1
Placing lower selected	m^3	85.5	140	R 11,970.00	3
Placing upper selected	m^3	85.5	140.00	R 11,970.00	3
Placing cemented subbase	m^3	114.0	150.00	R 17,100.00	7
Cement in subbase	ton	7.9	1,600.00	R 12,585.60	
Placing of G1 base	m^3	85.5	450.00	R 38,475.00	7
Prime	m^2	427.5	11.20	R 4,788.00	1
Tack	m^2	313.5	5.00	R 1,567.50	1
Asphalt	ton	54.7	1,667.00	R 91,218.24	
SUB-TOTAL				**R 270,511.74**	
Fixing/replacing/protection of services	m^2	570.0	94.43	R 53,824.36	14
Time related costs	Month	2.1	132,057.00	R 273,117.89	
SUB-TOTAL				**R 326,924.25**	
			TOTAL	**R 597,453.99**	**45.5**

If the construction cost only is calculated, the conventional pavement is cheaper than the bitumen stabilised pavement, but the services and time related cost of the conventional pavement is far more expensive, therefore the total combined costs of the pavements show clearly that the conventional pavement was not be the most economical option to choose on this project.

6 Conclusion

The innovative pavement design and construction methods specified, in this urban environment, where an abundance of services, pedestrians and traffic were present, was the most practical, economical and environmentally friendly solution for this project. The risk for running over time and the economical risk, due to unknown services, were reduced, for the client as well as the contractor.

The paving of a bitumen stabilised crushed stone on top of a stabilising grid was a first attempt of it's kind in Bloemfontein and monitoring of the pavement will be ongoing.

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