LOW COST HIGH BENEFIT IMPROVEMENTS TO BEN SCHOEMAN FREEWAY

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INTRODUCTION

Recent investigations into the condition of the continuously reinforced concrete (CRC) overlay on Ben Schoeman freeway revealed that the structural performance was still adequate after 12 years of service under exceptionally heavy traffic.

According to functional and structural investigations in 1985, structural failure of the previous asphalt pavement originated in the subbase, causing stress in the G1 base. This, in turn, resulted in a reduced base stiffness and eventual cracking and rutting in the asphalt surfacing. A decision was taken to construct a CRC overlay and additional 3,7 m wide lanes on the inside of both carriageways. The CRC was the most cost-effective of the alternatives investigated and was designed for a 20-year life-span with the provision that asphalt overlays would be required after 15 years.

Recent field measurements on the freeway between Buccleuch and Brakfontein interchanges included:

- a visual condition survey
- drilling of cores in the concrete pavement
- falling weight deflectometer testing across transverse cracks
- horizontal movement measurements across transverse and longitudinal cracks.

Results from this investigation showed that the structural performance of the CRC was still adequate with less than 1% of the pavement requiring local repair work. Therefore, at a relatively low maintenance cost to date, the CRC has rendered high benefits to the road user. An area between the Jukskei River bridge and Buccleuch interchange has been identified for the construction of experimental asphalt overlays to establish the best future option for an overlay.

Re-marking the pavement to allow for four lanes in both directions rather than three is a further low cost improvement that has been investigated. This will alsorender high benefits in terms of user time cost savings due to reduced traffic density and increased passenger car speed.

FIELD MEASUREMENTS

Visual condition survey

Because the Ben Schoeman is the only continuously reinforced concrete pavement (CRCP), of substance, in the country, no South African visual condition survey criteria or a standard condition survey sheet existed prior to the survey. An in-house workshop was, therefore, conducted to establish these criteria (**Table 1**) and to compile a visual survey sheet.

Table 1: Criteria for visual condition survey

Defect	**Degree**		
	1	**2**	**3**
Cracks	< 0,5 mm	0,5 - 2 mm	2 - 5 mm
Spalling	5 - 10 mm	10 –20 mm	> 20 mm*
Pumping	Discoloration	Fines	Material
Punch out	Number minor		Number severe
Patch	Number minor		Number severe
Seals	Uneven	Gaps	Out
Texture	> 1,0 mm	0,5 - 1,0 mm	< 0,5 mm
Drainage	Problem suspected	Drain slowly	Water standing
Accident	Few skid marks	Skid marks	Hits / Skids

* 2 or more spalls per crack

Only the slow lane could be assessed for cracking, spalling, pumping, punch-outs, patching, and joint seal condition, since the Ben Schoeman is the most heavily trafficked freeway in the country, with at least three traffic lanes in each direction. Surface texture, drainage, and accident data were recorded for the whole road.

Real criteria had also not yet been established for the condition assessment and, therefore, had to be compiled.

Apart from the joint seals in the longitudinal joints that need replacing as part of routine maintenance, there is very little that need to be done to the concrete pavement at present. Less than 1% of the CRC pavement require local repair work due to punch-outs or structural failure.

Coring

Based on the results of the visual condition surveys, ten positions for drilling cores in the pavement were initially selected at transverse cracks.

The first core was drilled at N1/21 km 7,2 on the northbound carriageway. During road construction, problems had been experienced at this specific position, due to excess slagment in the concrete mix. Although the surface had weathered considerably more at this point than the rest of the road and the core was drilled on a transverse crack, the concrete proved to be structurally sound, with the crack feathering out about two-thirds of the depth of the core (**Photo 1**).

The second core was drilled at N1/20 km 55,2 on the southbound carriageway. Once again, the core was drilled across a transverse crack that apparently showed signs of pumping. Although the crack was approximately 5 to 10 mm wide on the road surface, it also feathered out, about two-thirds through the depth of the core (**Photo 2**).

Finally, in an attempt to obtain a core that is cracked right through, a position was chosen at N1/21 km 3,8 on the southbound carriageway, where a transverse and random crack met and where pumping was also observed, (**Photo 3**). Unfortunately, the core had to be broken off, as the drilling process was slow due to the high strength of the concrete and the fact that reinforcing steel was encountered.

The above three cores led to the conclusion that the existing pavement was structurally sound and that no further drilling of cores was necessary. The cores also showed that there was no ingress of water into the asphalt beneath the CRCP at transverse cracks, since no stripping of asphalt was evident. Nor was there any movement of the CRCP relative to the asphalt, as there were no gaps between the CRCP and the asphalt (**Photo 4**). Signs of pumping on the surface were therefore defined as stains originating from an unknown source.

During construction of the CRCP in 1987/8, inadequate mixing of the cement and slagment did occur at times. The relevant sections of concrete were removed, but cores were taken from these sections prior to their being broken out. **Photo 5** shows to what extent one of these cores has weathered after 10 years of exposure to the elements.

Falling weight deflectometer testing

The structural condition of the pavement was assessed with the aid of the falling weight deflectometer (FWD). In essence, this entails measuring surface deflection resulting from an applied load of 40 kN at radial distances of 150 mm. Surface deflection is measured at 0, 200, 300, 450, 600, 900, and 1 200 mm from the centre of the load, representing the deflection bowl.

Twenty positions were selected for measuring deflection and relative movement across a crack. Ten of these coincided with those originally selected for drilling cores. Deflection averaged 0,091 mm with a standard deviation of 0,026 mm in the northbound direction, and 0,086 mm with a standard deviation of 0,043 mm in the southbound direction. Relative movement averaged 0,0055 mm with a standard deviation of 0,0018 mm in the northbound direction, and 0,0047 mm with a standard deviation of 0,0016 mm in the southbound direction.

Horizontal movement measurements

Eight transverse and four longitudinal cracks were chosen to measure horizontal movements in the CRCP over a 24 hour period. The environmental conditions prevalent at the time were recorded by measuring the surface temperature, relative humidity, wind speed and wind direction. No significant horizontal movements that could be detrimental to the performance of the pavement were detected.

EVALUATION OF CRCP

To the inexperienced eye the Ben Schoeman Freeway may appear to be in need of repair due to closely spaced transverse cracks. However, according to the design principles behind CRCP construction, the pavement has performed adequately. The CRCP is designed to form narrow cracks of 0,6 mm in width at an average spacing of 1,5 m. This is in contrast to a jointed concrete pavement where the allowable crack spacing is 4,5 m and allowable crack width is about 3,0 mm.

Stages of deterioration of a CRCP are:

- First stage : crack spacing decreases to < 1,0 m
- Second stage : spalling at top of cracks
- Third stage : relative movement at cracks; pavement becomes flexible
- Fourth stage : pumping and stress on subgrade
- Fifth stage : punch-outs.

Movement occurs in the pavement from the third stage onwards, ie subgrade support, k, is gradually lost.

The relationship between load, slab stiffness, subgrade support, deflection and crack/joint configuration can be illustrated by the following equation:

Deflection, $$y = \frac{CP}{\sqrt{Dk}}$$

Where: y = deflection (mm)
C = 0,12 for interior loading
= 0,43 for edge loading
= 0,90 for corner loading
P = load (kN)
k = subgrade support

and where $$D = \frac{Eh^3}{12(1 - \mu^2)}$$

with: E = elastic modulus (MPa)
h = layer thickness (mm)
μ = poisson's ratio

This shows that deflection increases with lower values of k. Furthermore, deflections are influenced by the thickness of the layer (h) to the power of three. This emphasizes the importance of correct as-built information when back-calculating deflections to determine individual layer stiffnesses.

Load transfer across cracks in the CRCP is essential. When a crack develops through the pavement and this opens up, load transfer is reduced and C increases either to the edge loading, or even the corner loading value, which eventually leads to secondary cracking and punch-outs.

Analysis of the condition survey of the Ben Schoeman freeway shows that crack spacings of less than 1,0 m are very localised. Spalling of the cracks does occur, but mostly as a warning condition.

The third stage has been investigated by drilling cores to determine whether the cracks had developed fully through the concrete. Pumping was observed, but was found to be staining originating from other sources. However, some localized areas had reached the fifth stage, where punch-outs had developed and full-depth repair work was required. These were located mainly where a poor Portland cement/slagment mix had occurred during initial construction.

All pavement material properties and layers were used to facilitate the mechanistic modelling of the pavement. Two computer programs were used to back-calculate layer stiffness from surface deflections, namely EVERCALC and ELSYM5. Apart from measured deflections, these programs needed current pavement structure as input. This was obtained from the background information already gathered. A pavement model could, therefore, be compiled for each FWD test position.

The pavement layer thicknesses used in the models and the average back-calculated stiffnesses are summarized in **Table 2**.

Table 2: Summary of pavement models and back-calculated stiffnesses

Carriageway/Layer	Layer thickness (mm)	Average layer stiffness (MPa)
Northbound (slow lane)		
Surface	170	66 500
Base	100	3 285
Subbase	325	490
Subgrade	-	95
Northbound (climbing lane)		
Surface	170	60 000
Base	30	1 335
Subbase	100	390
Subgrade	-	100
Southbound (slow lane)		
Surface	170	62 300
Base	100	3 580
Subbase	325	740
Subgrade	-	90

Adequate structural performance of the CRCP suggests that the layer is still uniform and homogeneous, with load transfer across the transverse cracks. The CHEVRON (ELSYM5) theory could, therefore, be used to determine the e-moduli.

Current and projected vehicle movements were used to determine the projected total number of design axles. Given the projected future traffic volumes and characteristics, the structural capacity (in years) of the pavement could be assessed from its remaining life.

Structural performance of the CRCP was still found to be adequate, with a remaining life of approximately 10 years and no overlay required as yet. Between Allandale and Buccleuch interchanges, longitudinal cracks have developed due to expansion of the concrete around horizontal curves. These cracks need to be sealed to prevent the ingress of water.

All the longitudinal joints along the entire project length have to be resealed. Concrete failures requiring full-depth concrete repair had occurred in less than 1% of the pavement. Repair patches should be continuously reinforced with steel, tied or welded to the reinforcing steel in the existing slab to provide load transfer across joints and slab continuity. Full-depth asphalt repairs should not be used in CRCP and existing asphalt patches should be removed and replaced with continuously reinforced concrete patches.

Although the possibility of a structural asphaltic overlay was mentioned in the original 1986 report, there is no need as yet for such an overlay, since the road is still structurally sound with adequate skid resistance, according to current testing methods. However, high-speed testing techniques, for example the Aran, are recommended prior to final design.

The area between the Institute Bridge to Buccleuch (southbound) has been identified as potentially the best position for an experimental asphalt overlay. Selection of this section was based on the number of longitudinal cracks that occur along this section and the need to improve the surface characteristics where vertical cross-over currently causes aquaplaning during rainy conditions.

RE-MARKING THE PAVEMENT

Previous studies were conducted to determine options for upgrading the Ben Schoeman freeway. Widening the freeway was investigated but appeared to be a very expensive option. The possibility of re-marking the existing traffic lanes to create an additional lane in each direction along the entire length of road was investigated as an alternative to physically widening the freeway. Re-marking would result in lane widths of 3,4 m and a left-hand shoulder width of 1,7 m. These factors (lane widths and distance to obstacles alongside) are known to affect the capacity of a road.

Current levels of service, density and traffic speed were analyzed along existing sections where three traffic lanes exist to determine the feasibility of this proposal. The Highway Capacity computer software, based on the 1997 Highway Capacity Manual methodologies was used to evaluate the various traffic sections.

The analyses showed that the section between Buccleuch and Allandale interchanges experiences the worst traffic flow conditions during both peak hours for both directions of travel. Operating conditions on the N1 are generally worse during the PM peak hour for the northbound section under consideration. Congestion in the southbound direction is mainly due to the confluence of two major traffic streams – the main traffic along the freeway and the merging traffic from Allandale interchange.

Results from the investigation indicate the feasibility of re-marking the pavement from three to four traffic lanes, and point to a significant impact on expected traffic flow conditions, especially during peak hours. Reduced traffic density and increased passenger car speed would be the main advantages.

On the other hand, the traffic flow analyses for the off peak periods have shown that, based on the assumptions in the Highway Capacity Manual, speeds dropped rather than increased due to the effect of narrower traffic lanes, but that the level of service and density improved.

Time is costly as well and lost time have a negative impact on the economy. The traffic flow patterns along the Ben Schoeman freeway indicate high commuter traffic between the Pretoria and Johannesburg areas. Most of these trips are business trips, which implies that time-cost could be enormous considering annual daily traffic of between 120 000 and 165 000 vehicles along certain sections of the route.

An economic evaluation, based on the advantage that **passenger cars** only would gain from the proposed upgrades in terms of travel time-savings for passenger cars over the sections evaluated, was conducted. It was found that, for travel-time cost values of between R5.00 per hour for low-income groups to R80.00 for high-income groups, the estimated benefit for the peak periods as assumed, could be approximately R8.0 million for the first year of implementation.

It is obvious that this low-cost solution to upgrade the existing facility from an F to a D level of service, will afford high benefits through significant cost-savings to road-users.

CONCLUSIONS

It is already 15 years since the futuristic design of the CRC overlay on the N1 Ben Schoeman freeway and some 12 years since its implementation. Moreover, the capacity of the freeway has been increased during this period by adding an extra 3,7 m wide lane on the inside of both carriageways. Recent investigations revealed that the structural performance of the CRCP is still adequate and has therefore been a high benefit to road users, due to relatively low maintenance costs during its years under operation. Re-marking the existing facility will significantly improve the level of service during peak hours at minimum cost, with further high benefits through significant cost-savings to road-users.

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Photo 1: km 7,2 N - Surface weathering due to high slagment content

Photo 2: Transverse crack showing signs of “pumping”

Photo 3: Intersection of transverse and random cracks with “pumping”

Photo 4: Good adhesion between asphalt and concrete

Photo 5: Weathering of concrete containing badly mixed cement/slagment mixture, after 10 years' exposure to elements

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KEY QUALIFICATIONS

Pavement design engineer with 15 year's experience in the theoretical analysis of road pavements. Proficient in evaluating both asphalt and concrete pavements by implementing mechanistic design methods. Practical site experience in inter alia the rehabilitation of the N2 Cape concrete road - a jointed concrete pavement overlaid with a bitumen rubber single seal and bitumen rubber overlay, as well as in the construction of the N1 through Du Toitskloof – a dual carriageway freeway through an environmentally sensitive area. Obtained MIng at the University of Stellenbosch in 1988. Presently studying towards a PhD at the University of Pretoria.