CRCP on the Ben Schoeman Freeway – No Alternative

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Abstract

For the commuter traveling between Pretoria and Johannesburg, the name "Ben Schoeman" nowadays has become synonymous with traffic congestion and delays. Towards the end of the previous century, the Ben Schoeman was already the busiest road on the African continent with the Average Annual Daily Traffic on some road sections close to 150 000. For the South African Civil Engineer, however, the Ben Schoeman can be viewed from a totally different perspective as it is the only continuously reinforced concrete pavement (CRCP), of substance, in the country. The increasing traffic volume and a traveling public becoming more and more environmentally conscious, but intolerant to traffic delays, was only one of the issues facing the Engineers who, once again, had to develop an innovative long-lasting concrete pavement repair solution. Considerable research went into developing and testing rapid repair concrete mix designs as the worldwide philosophy on freeways is: Get in, get out and stay out. The CRCP has proven to be a low-cost high-benefit solution with only 0.2% of the pavement surface area requiring local repair work after nearly 20 years of service. The paper gives an overview of the history of the Ben Schoeman, the investigation into the CRCP over a number of years and the fast track concrete repair measures implemented during a recent repair contract. A comparison is made between the behavior of the CRCP and that of jointed concrete pavements (JCP) over time.

Introduction

For the commuter traveling between Pretoria and Johannesburg, the name "Ben Schoeman" nowadays has become synonymous with traffic congestion and delays. Towards the end of the previous century, the Ben Schoeman was the busiest road on the African continent (Hanekom 2000b) and by 2006 the Average Annual Daily Traffic (AADT) on some road sections was already close to 150 000 (Kong Kam Wa et al. 2007).

For the South African Civil Engineer, however, the Ben Schoeman can be viewed from a totally different perspective as it is the only continuously reinforced concrete pavement (CRCP) of substance in the country. At the time of design and construction of the CRCP it was viewed as an innovative design method and, due to premature failure of some jointed concrete pavements in South Africa, regarded with skepticism.

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The increasing traffic volume and a traveling public becoming more and more environmentally conscious, but intolerant to traffic delays, were only two of the issues facing the Engineers who, once again, had to develop an innovative long-lasting concrete pavement repair solution. Considerable research went into developing and testing rapid repair concrete mix designs (Kong Kam Wa et al. 2007) as the worldwide philosophy on freeways is: Get in, get out and stay out.

The CRCP has proven to be a low-cost high-benefit solution with only 0.2% of the pavement surface area requiring local repair work after nearly 20 years of service.

The following paper gives an overview of the history of the Ben Schoeman, the investigation into the CRCP over a number of years and the fast track concrete repair measures implemented during a recent repair contract. More important, however, is the comparison of the behavior of the CRCP versus the behavior of jointed concrete pavements (JCP) over time.

Where did it all start?

The original asphalt pavement was constructed during 1969 and opened to traffic during 1970. The pavement structure was as follows:

30 mm	Continuously graded asphalt (AC)
200 mm	Crushed stone base compacted to 88% of apparent density (G1)
100-150 mm	Stabilized gravel subbase compacted to 95% of modified AASHTO density (C3)
2 x 150 mm	Selected gravel subgrade compacted to 93% of modified AASHTO density (G7 + G9)

During 1973/4 a strengthening overlay, varying from 25 mm of open graded asphalt to 40 – 75 mm gap-graded asphalt with rolled-in chips was constructed (NVK 120104, 1986).

Functional and structural investigations in 1985 indicated that failure of the asphalt pavement originated from the subbase, causing stress in the G1 base with reduced base stiffness and eventual cracking and rutting in the asphalt surfacing.

Although Packard (1973) had already developed a computer program for airport pavement design in the United States, it was not available locally and the trusted Yoder and Witczak (1975) was used to develop a simple computerized routine based on the Westergaard concrete pavement analysis formulae. Given the known design parameters at that stage, the thickness of the CRCP that was required for the majority of the road width was calculated at only 75 mm. This was of course not practical, as it would not have rendered sufficient cover to the reinforcing steel.

After incorporating all practical design considerations, a 150-mm thick CRCP, designed for a 30-year lifespan, was constructed over the old asphalt pavement during 1987/88. Additional 3.7-m wide lanes, also with 150-mm thick CRCP on top were added on the inside of both carriageways. Climbing lanes with a CRCP thickness of 170 mm were added to both the northbound carriageway and the southbound carriageway in four locations. Where the road had to be re-graded underneath bridge structures, the CRCP thickness was 185 mm.

The CRCP was designed to receive an asphalt overlay after 15 years, which implies that repair work should have been conducted during 2003 already. However, due to fact that the facility has been running over capacity for a number of years, other investigations were also conducted, such as remarking the pavement from three to four lanes, tolling the facility and even constructing an alternative route.

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 (Hanekom et al. 2000a).

Table 1: Criteria for visual condition survey (Hanekom et al. 2000a)

Defect	Degree		
	1	**2**	**3**
Cracks	< 0.5 mm	0.5 – 2 mm	2 – 5 mm
Spalling	5 – 10 mm	10 - 20	> 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

Due to the high traffic volume (the Ben Schoeman being the most heavily trafficked freeway in the country with at least three traffic lanes in each direction), only the slow lane could be assessed for cracking, spalling, pumping, punch-outs, patching, and joint seal condition. 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 needed replacing as part of routine maintenance, there was little that had to be done to the concrete pavement. The pavement area that required local repair work due to punch-outs or structural failure was calculated at less than 1% of the total surface area during 1999. The area of the patches repaired (typically degree 3) during the recent fast track repair contract, calculated as a percentage of the total surface area, was only 0.2%.

Coring. During the previous investigation in 1999 ten positions were initially selected for drilling cores in the pavement. These positions were based on the results of the visual condition survey.

The first core was drilled at N1/21 km 7.2 on the northbound carriageway where the road surface had weathered considerably more than the rest of the road. During road construction, problems had been experienced along this section as the component of the ground granulated blast-furnace slag (ggbs) in the 70:30 – cement:ggbs in the concrete mix was exceeded. Although 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 across a transverse crack that apparently showed signs of pumping. Although the crack was approximately 5 to 10 mm wide on the road surface, the crack also feathered out about two-thirds through the depth of the core (Photo 2).

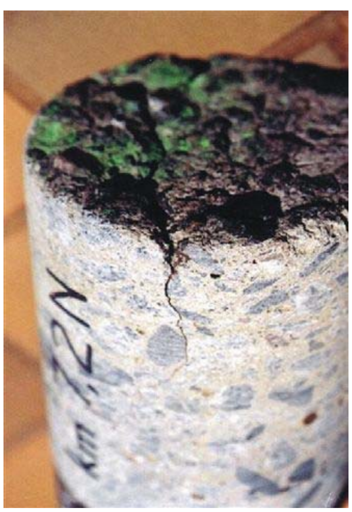

Photo 1: Surface weathering due to high ggbs content (left)
Photo 2: Transverse crack showing no signs of pumping (right)

Finally, in an attempt to obtain a core that was 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 first three cores confirmed 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.

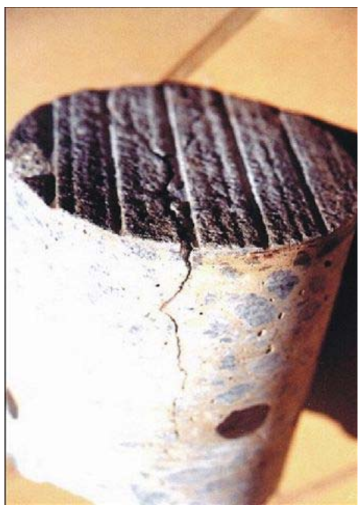

Photo 3: Intersection of transverse and random cracks (left)
Photo 4: Good adhesion between asphalt and concrete (right)

During construction of the CRCP in 1987/8, inadequate mixing of the cement and ggbs 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 the extent to which one of these cores had weathered after 10 years of exposure to the elements.

Photo 5: Weathering of concrete containing badly mixed cement/ggbs mixture, after 10 years' exposure to 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 deflections were 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 cracks. Ten of these coincided with those originally selected for drilling cores. Deflections 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 movements 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

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.

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 secondary cracking and punch-outs occur.

Analysis of the condition survey of the Ben Schoeman freeway in 1998 showed that crack spacings of less than 1.0 m occurred in localised positions only. Spalling of the cracks had occurred, but was mostly at a warning level in terms of the visual assessment.

The third stage was investigated by drilling cores to determine whether the cracks had developed fully through the concrete. Apparent pumping had been 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 excessive amounts of ggbs and inadequate amounts of cement had been batched into the concrete during initial construction.

All pavement material properties and layers were used to carry out mechanistic modelling of the pavement. At the time of the initial investigation the software package cncPave did not exist yet and 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.

Adequate structural performance of the CRCP suggested that the layer was still uniform and homogeneous, with load transfer across the transverse shrinkage 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 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 had developed due to expansion of the concrete around horizontal curves. These cracks were sealed to prevent the ingress of water.

All the longitudinal joints along the entire project length had to be resealed. Concrete failures requiring full-depth concrete repair had occurred in less than 1% of the pavement.

Rapid Hardening Concrete Mixes

Although the detail design, project specification and documentation for the joint sealing and repair of localized failures on the Ben Schoeman was completed during 1999, the project was shelved as there was talk of tolling the road and SANRAL did not want to conduct improvements, while the toll strategy was not approved. However, the fact that the project was shelved did not stop the pavement from deteriorating further and where sealing of the longitudinal joints were already overdue in 1999, it became imperative that something be done.

A lot of time and attention to detail was spent on the design of the accommodation of traffic; however, during the lapse in time (between 1999 and 2006), the traffic volume increased, which reduced the margins within which construction activities could take place even more. Theoretically two lanes must be open to traffic at all times and to avoid major traffic back up on a road that is operating at level of service F (where level of service ranges from A – free flow to F – forced or breakdown flow) most of the time, it implied that the repair work could only be conducted overnight. Furthermore, each night shift was limited to 8 hours from 21:00 in the evening to 05:00 the next day.

Fortunately South Africa is not the only country that has been experiencing a growth in vehicle traffic volume while, at the same time, roads have been deteriorating. Several rapid hardening concrete mixes, with which the road can be opened to traffic within 3 to 4 hours of mixing, have been developed worldwide.

Once again the Design Engineers on the project were faced with the challenge to implement international best practice and adjust it to suit South African conditions. The opening strength criteria, the minimum percentage shrinkage that would be allowed and durability parameters were set through research and a series of laboratory tests, where after the optimum product could be selected. This entire process has been described in a paper that has been presented at the 26th Annual Southern African Transport Conference during July 2007 (Kong Kam Wa et al. 2007) and it is not deemed necessary to go into further detail in this paper.

Construction of Patches with Rapid Hardening Concrete

Once the repair areas were identified (Photo 6), they were scanned with ferro scanners to locate the position of existing steel reinforcement. This was in order to cut marked areas within reinforcement boundaries so as to minimize cutting of further bars with the inevitable over cuts. It was decided from the outset, due to time restraints, that the concrete would be cut full depth and lifted out in full panels. The following is a summary of the construction sequence and observations made during the process:

- Saw cut into panels of 1.5 x 1.2 m. Cutting of heavily reinforced concrete needs specially designed diamond blades (Photo 7).
- Drill holes and fix bolts into panel to lift it out (Photo 8).
- Lift out panels. A 12 ton metre truck mounted crane was used to lift out the panels (± 1 ton). However, lifting equipment must be rated at 10 tons as concrete tends to adhere to the underlying layer.
- Drill tie bars (longitudinal and transverse). A 2000 Watt rotary hammer drill mounted horizontally on rails with adjustable depth settings was used. Tie bars were placed using a 1250 Watt rotary drill to 'spin' the bar mixing a two part epoxy on embedment. It was found that the position of distribution bars in the CRCP pavement repairs determined the transverse crack spacing of the repaired area. For instance, transverse steel placed at 1.2 m centre to centre induced cracks 1.2 m apart.
- Scabble all vertical faces.
- Re-instate all longitudinal, main and transverse distribution steel (Photo 9).
- Prime all vertical faces with concentrate of Contec QSF binder.
- Load and mix pre-weighed and bagged aggregate, sand and cement in a pan mixer. Quality control was achieved by pre-weighing and bagging of aggregates and binders in a controlled area.
- Place concrete using high frequency poker vibrators and high frequency heavy duty screed beam. The high frequency is essential to achieve good compaction of the mix.
- Finish concrete with hand floats and leveling beam. Hand floats give acceptable finish on small widths. Bull floats should be used on widths greater than 2.5 m. It was found that workability of the mix is good at temperatures between 12 and 18ºC. Aggregates were stored in a cold room at 17ºC in order to slow down the hydration process and allow enough time to finish off the concrete. At this temperature working time was a maximum of about 15 minutes. This means the mix behavior is very critical and requires constant supervision.
- Finish off surface texture with soft broom (micro texture) and spring steel tine (macro texture).
- Cure with a resin based curing compound (Photo 10) and, in cold weather (night time), a thermal blanket to retain heat (Photo 11).


Photo 6: Pop-out in slow lane – temporarily repaired with asphalt (left)
Photo 7: Saw-cutting along edge of repair patch (right)


Photo 8: Anchors fixed to lift out failed concrete (left)
Photo 9: Reinforcement steel in place – note tie-bars (right)


Photo 10: Repaired with rapid hardening concrete (left)
Photo 11: Covered with a thermal blanket (right)

The time window to complete the construction process was from 21:00 PM to 05:00 AM. Like any fast-track construction, well-planned construction sequencing is imperative. Apart from the slab saw cutting which is done on the night before, the average duration of the activities is as follows:

- Lifting of panels: 0.5 hrs
- Drilling tie bars, scabbling, cleaning out and placing steel: 1.5 hrs
- Pouring concrete at a rate of 1.75 m^3/hour: 2 hrs
- Curing to achieve minimum strength at opening: 4 hrs

Observations during Repair Work

The following paragraphs summarize some visual observations that were made during repair work to some of the concrete pavements across South Africa. The condition of the subbase beneath each concrete pavement was noted in particular.

These observations are in direct relation to the structural capacity of the concrete pavements, in essence the ability to transfer traffic loads across transverse cracks/joints. Little or no voids imply good load transfer capacity as there is little to no relative movement at the joint/crack and no pumping of fines due to the ingress of water.

All of the pavements mentioned, except the Ben Schoeman are jointed concrete pavements.

National Route 2, Sections 26 & 27. During the project: “Replacement of Joint Seals and Concrete Pavement Repair Work: National Route 2, Sections 26 & 27: Umdloti River to New Guelderland (N2/26 & N2/27 2005)” some broken concrete slabs were also repaired.

Well-timed resealing of a jointed concrete pavement is of utmost importance. Fortunately this is a Toll Road and the funds generated could be implemented timeously to reseal the joints and repair the pavement.

Defects noted prior to rehabilitation included corner breaks, longitudinal cracks and failure of stitching done across both longitudinal and transverse cracks. Little to no distress was observed in the subbase after removal of the concrete.

The area of the patches repaired as a percentage of the total surface area, some 12 years after construction, was 0.23%. During this contract, however the main component was not concrete repair work, but joint resealing.

National Route 3, Section 1. Some repairs to broken concrete slabs at the Mariannhill Toll Plaza on National Route 3, Section 1 (km 26) were also included in the project which was carried out in 2004/5 (N2/26 & N2/27 2005). The pavement at the Mariannhill toll plaza was completed in 1987 (at the same time as the Ben Schoeman was constructed). The original pavement structure consisted of 225 mm un-reinforced jointed concrete with un-doweled transverse joints on two 150-mm thick cement stabilized subbase layers (C3). By 2003 numerous slabs were cracked either longitudinally or transversely, with water and fines pumping out at the joints (Photo 12).

Photo 12: Longitudinal crack in un-doweled jointed concrete pavement

After removal of the concrete slabs, erosion trenches were observed beneath both the longitudinal and the transverse construction joints. These erosion trenches were up to a meter wide in places, and as deep as 100 mm, in other words, two-thirds through the upper subbase layer (Photo 13). A stiff mixture of soil and 5% cement was used to reinstate the subbase levels, prior to repairing the concrete slabs.

Photo 13: Erosion trenches in subbase beneath transverse and longitudinal joints in concrete pavement

The trenches observed beneath the joints were a clear indication that there was poor load transfer at the joints in both directions, but also that water got trapped inside the pavement.

National Route 3, Section 2. During the contract mentioned above, repair work was also done on both the northbound and southbound carriageways of the jointed concrete pavement on National Route 3, Section 2 (km 13.6 – km 15.0). The pavement consisted of 235 mm un-reinforced concrete with un-doweled transverse joints and keyed and tied longitudinal joints and was completed in 1996 (eight years after the Ben Schoeman had been completed). In this instance the subbase consisted of 100 mm of recycled asphalt. Once again, after removal of the broken concrete panels, it was observed that there were erosion trenches beneath both the longitudinal and transverse joints. The trenches were up to 750 mm wide and in some places right through the 100 mm asphalt subbase. The asphalt was stripped to such an extent that it looked like mud.

This road section is part of a joint resealing contract that was conducted during 2007.

National Route 1, Sections 19 & 20 (Johannesburg Western Bypass). The experienced pavement engineer may reason that the observations made on the above mentioned jointed concrete pavement road sections are logical, as these roads are in Kwazulu-Natal, where it is known that the Weinert-N-Value is less than 2 (South Africa is divided into three macro-climatic regions based on rainfall, namely: wet – $N < 2$, moderate – $2 < N < 5$ and dry – $N > 5$) (Weinert 1980). In other words it can be expected that the pavement materials will be subjected to chemical weathering due to the high rainfall, but also to mechanical weathering due to the high volume of heavy vehicles on the road.

However, on National Route 1, Sections 19 & 20 (part of the road section known as the Western Bypass around Johannesburg – leading up to the Ben Schoeman) major repairs to the jointed concrete pavement had been carried out during 1995/96. This 235-mm thick jointed concrete pavement on a 100-mm thick cement stabilized subbase (C1) was constructed during 1982.

Erosion of the subbase had occurred to such an extent that faulting had occurred in many places and the levels had to be reinstated through grouting, slab-jacking and extensive repair work.

National Route 1, Sections 20 & 21 (Ben Schoeman). The CRCP on this section was designed to receive an asphalt overlay after 15 years, i.e. 2003. However, a small section has only been sealed with a 13.2 mm bitumen-rubber single seal as part of the recent repair work contract in 2006/2007.

During the 2006/2007 repairs that were conducted on the Ben Schoeman, the following were noted:

- No pumping was observed.
- No voids were observed beneath the concrete.
- All the underlying asphalt was in a good condition – no stripping was observed.
- No deterioration of the asphalt subbase was observed beneath joints or cracks where repair work had to be carried out.
- Most of the repairs were necessary as a result of pop-outs.
- The majority of the repairs were in the slow lane.
- The subbase asphalt had adhered to the concrete in 80% of the repairs areas.
- In many places where longitudinal cracks were repaired, the subbase adhered to the base of the concrete on one side of the crack, while the other side was completely free.
- In some places cracks were observed in the subbase, but there was no indication of such cracks influencing failure of the concrete.
- Steel reinforcement in transverse cracks was not corroded.
- Existing reinforcing was always at mid-depth of the slab.
- In all the areas where stitching of the longitudinal joint was done, the 12 mm diameter high-tensile steel (Y12) tie-bars had snapped.
- At most of the longitudinal cracks, which were 10 mm wide in some places, all aggregate interlock was lost, yet there was no faulting or any sign of distress in the subbase.
- The transverse texturing cut into the concrete surface during 1994 to improve skid resistance had lost approximately 1 mm in depth since then due to surface abrasion.

- The temperature difference between the top and the bottom surfaces of the CRCP was $5^{o}C$ - summer hotter on top, winter hotter underneath (all measured at night).
- Definite transverse movement could be detected when inspecting the silicone joints in early evening and early morning.
- A lot of the concrete on the southbound carriageway between Allandale and Buccleuch interchanges was very dark in color; almost black on the bottom half.

Only 0.2% of the pavement surface area required local repair work after nearly 20 years of service.

Summary and Conclusions

The preceding paper gives an overview of one of the most renowned highly-trafficked commuter corridors in South Africa, with the Average Annual Daily Traffic close to 150 000 on some road sections. Whereas the pavement was initially constructed as a standard asphalt surfaced road, innovative designs have led to a relatively low-cost high-benefit facility. Not only was the CRCP overlay that has been constructed during 1987/88 an innovative and daring pavement design for its time, but the recent rapid repair measures that were implemented, compliment a facility where things seems to have been done correctly.

Although the technologies implemented on the Ben Schoeman has been a “first” for South Africa, ever since its construction, it also stands as an example of what should be done. If the economy of scale warrants the construction of a concrete pavement, roads situated in high rainfall areas that are also subjected to high volumes of heavy vehicles have to be constructed using CRCP and not JCP.

One of the assumptions made during the 1999 investigation was that adequate structural performance of the CRCP suggested that the layer was still uniform and homogeneous, with load transfer across the transverse shrinkage cracks. This assumption, amongst others, was found to be true during the recent repair work to the CRCP. No signs of pumping either beneath transverse shrinkage cracks or beneath the longitudinal joints were observed.

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NOTE: Reference to Hanekom, A.C. is the same person as Brink, A.C.; the former being the married name and the latter the maiden name of the main author.