# THE USE OF INNOVATIVE TECHNOLOGIES TO FACILITATE RAPID REPAIR OF CONCRETE PAVEMENTS: A CASE STUDY FOR SOUTH AFRICA

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**ABSTRACT**

Increasing traffic volumes and a travelling public that is becoming more and more environmentally conscious but intolerant to traffic delays, are common issues facing the authorities in urban areas across the world. This results in great pressure on engineers to develop more innovative ideas for long lasting pavement repairs.

The situation in South Africa is no different albeit on a smaller scale relative to countries like the United States. Repair on the urban roads in Gauteng is becoming increasing challenging especially when no capacity upgrade has been undertaken for a number of years. This is particularly true for the Ben Schoeman freeway which is the main link between Johannesburg and Pretoria.

This paper discusses some of the latest progress made in concrete technology as a result of these challenges. It focuses on the implementation of these technologies on the Ben Schoeman freeway from design to construction. Many of the concrete pavements in South Africa are nearing the end of their design lives and implementing new repair methods as well as sharing the good and bad experiences amongst practitioners, contractors and the client is becoming increasingly important if not a must.

## 1. INTRODUCTION

The Ben Schoeman freeway is one of the main corridors connecting Johannesburg and Pretoria in the Gauteng province. The latter is the industrial hub of South Africa with historical growths greater than the national economy. The Ben Schoeman freeway is the first and only freeway in South Africa where a Continuously Reinforced Concrete Pavement (CRCP) overlay was applied over the full width of the carriageway. That was done in 1987/88 due to the strategic importance of the freeway. The CRCP performed very well during the past 15 years. However, during the last few years the number of punch out failures occurring on the pavement has been on the increase mainly due to water ingress through the joints. With the Average Annual Daily Traffic bordering on 150000 on one section of the freeway, any repair activities on the freeway, even during week-ends, impacts severely on the traffic. Concrete repairs on a CRCP make it even worse due to the generally longer road closures required. This necessitates the use of innovative technologies for the concrete repairs so as to minimize the road user cost and at the same time reduces the risk of accidents which is fairly high during construction.

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The aim of this paper is to summarise some of the innovative repair methods that were employed on the Ben Schoeman freeway and share some of the experiences gained on this particular contract. Although a literature survey on the topic provided a lot of insights on what is being done overseas and what can go wrong, some adaptations to local circumstances were still required.

## 2. CHALLENGES OF URBAN CONCRETE PAVEMENT REPAIRS

It is a well known fact that repairs to CRCP is slightly more difficult than repairs of plain or dowelled Jointed Reinforced Concrete Pavement (JRCP). However, it becomes a challenge when such repairs are needed under a heavily trafficked freeway such as the Ben Schoeman. The freeway, with its two system interchanges and five access interchanges operates at a level of service F most of the times and is very sensitive to incidents. It is thus not surprising that whenever remedial actions are required on such freeways, traffic accommodation and road user safety during road closures become a major issue.

Evidently, the impact of the repairs on the road user can be reduced significantly if these are done during off peaks hours. Past experiences on this freeway however, have shown that week-end closures still resulted in huge delays in traffic especially if the repairs are in the middle lane. As a result the brief for the Ben Schoeman contract was to undertake all repair works at night. While the amount (or extent) of the works can be adapted to fit one night shift before re-opening the freeway to traffic in the morning, a major challenge remains in designing a concrete mix that will gain sufficient early strength by the end of the night shift.

Analysis of the traffic data showed that theoretically two lanes must always be open to traffic at all times. Furthermore, to avoid major traffic back up each night shift was limited to 8 hours from 21.00 p.m. to 5.00 a.m. the next day. This meant that the contractor will have the challenging job of establishing his team, break and remove the demarcated failed concrete, drill and epoxy new tie bars, mix and pour new concrete, all within eight hours less the time required for the concrete to set. While this has never been attempted in South Africa, a literature review on the subject revealed that it is being done overseas albeit recently.

## 3. NEW GENERATION OF RAPID HARDENING CONCRETE MIXES

Many proprietary products (e.g. polymeric concretes) that can reach strength in the limited time dictated by the authorities / road users are traditionally aimed at small and localised repairs and not really for large-scale production. A literature review on the subject revealed that this is not only true in South Africa but overseas as well. In the USA however, due to the challenge of urban concrete repairs, there has been an increase in new generations of high early strength concrete which enables large scale concrete repairs to be done in shorter time and in harsher conditions. With these concrete mixes, the road can be opened to traffic within 3 to 4 hours of mixing. It is mainly the development and advances in admixtures in recent years that made this possible.

Unfortunately many of these concrete mixes are proprietary products which not only are not available in South Africa but also, the exact composition of admixtures used is unknown. A typical example of such concrete is the one developed by Degussa Admixtures (Bury and Nmai, 2005) in the US in collaboration with California Department of

Transport (CALTRANS). The Novel High Early Strength Concrete (NHESC) as it is called relies on a unique combination of innovative admixtures resulting in workability, rheology control, and rapid strength performance for economical concrete repairs. It achieves its early strength performance, in part, by using special polycarboxylate-based high-range, water-reducing admixtures for efficient cement dispersion and lowering of the water-to-cementitious materials ratio.

Another branded product that has recently been experimented with by CALTRANS and the University of California, Berkeley (UCB) is “Rapid Set” which is a proprietary cement containing calcium-sulfo-aluminate as the main component (Lee *et al*, 2001). The product was used successfully in 1999/2000 in a major rehabilitation contract near Los Angeles, on Interstate 10 – a freeway carrying 240,000 vehicles a day. It is interesting to note that the Fast Setting Hydraulic Cement Concrete (FSHCC) produced using the Rapid Set cement also contains a retarder and a superplasticizer which needed adjustment for any 5ºC change in ambient temperature to maintain constant workability and set time of mix. Apart from some consistency problems and formation of cement balls inside some of the mixer trucks, the mix seems to have achieved the targeted strengths without any problem.

Notwithstanding the above promising results, more than one reference (NCHRP, 2004; Bury and Nmai, 2005; NCHRP, 2005) highlighted the need to investigate the drying shrinkage of the final concrete product. This is because of the relatively high cement contents and accelerator dosages used in these mixes. Based on the latest research (NCHRP, 2005) undertaken under auspices of the National Cooperative Freeway Research Program, it was found that some of the Early-Opening-to-Traffic (EOT) concrete mixes (both in the field and laboratory) had inadequate air voids content in the hardened state. In addition, low magnification with the petrographic optical microscope revealed a less homogeneous paste and more microcracking in 6- to 8-hour EOT concrete as compared to the 20- to 24-hour mixes. Interestingly, in spite of these findings, it appears that durability of the mixes tested does not seem to have been compromised.

## 4. OPENING STRENGTH CRITERION FOR BEN SCHOEMAN FREEWAY

While it is necessary to develop concrete which develop strength ultra rapidly, research has shown that the road can be opened to traffic well before the target 28-day strength has been reached. Based on the literature survey, the opening criterion used by different agencies in the world varies depending on local conditions. Some are based on minimum strength while some on minimum curing time. The American Concrete Pavement Association (ACPA, 1989&1994) recommends the former because strength gain is a function of the cement hydration and the environment and directly relates to load carrying capacity of a pavement. Basically the strength necessary to allow vehicles onto a new pavement will depend on a number of factors:

- Type and weight and number of anticipated loads during early aged period.
- Location of loads on slab
- Concrete Modulus of Elasticity
- Pavement design (new construction, unbonded/bonded overlay, overlay on asphalt)
- Slab thickness
- Modulus of Subgrade reaction or foundation support
- Edge support condition (widened lane or tied concrete shoulder etc.)

Assuming 0.6m traffic offset from the lane edge, ACPA (ACPA, 1994) provides recommended opening flexural strengths for the following variables: slab thickness, slab support and the number of loads carried by the slab before the concrete reaches design strength. **Table 1** summarises the recommendation for a 175mm and 200mm thick slab.

**Table 1: Flexural strength requirements (third point loading test) for opening concrete pavements to use by public traffic (ACPA, 1994).**

| SLAB THICKNESS (mm) | FOUNDATION SUPPORT, K (MPa/m) | MODULUS OF RUPTURE FOR OPENING (MPa) TO SUPPORT ESTIMATED DAILY E80S REPETITIONS TO SPECIFIED STRENGTH* | | | | |
|---|---|---|---|---|---|---|
| | | 100 E80S | 500 E80S | 1000 E80S | 2000 E80S | 5000 E80S |
| 175 | 27.2 | 2.6 | 2.8 | 3.0 | 3.1 | 3.3 |
| | 54.3 | 2.1 | 2.3 | 2.5 | 2.6 | 2.8 |
| | 135 | 2.1 | 2.1 | 2.1 | 2.1 | 2.2 |
| 200 | 27.2 | 2.1 | 2.3 | 2.3 | 2.5 | 2.6 |
| | 54.3 | 2.1 | 2.1 | 2.1 | 2.1 | 2.3 |
| | 135 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 |

Note *: The traffic is estimate of the total one-way E80sthat will use the pavement slow lane between time of opening and time concrete reaches design strength (usually 28-day strength)

The average daily E80s (ADE) on the worst section of the Ben Schoeman (Allandale to Buccleuch) was 7658 in 2004. This is equivalent to 3829 per direction. Assuming an ADE of 4000, concrete thickness of 200mm and also assuming that the concrete will reach design strength within 24 hours of opening, the minimum opening flexural strength according to **Table 1** is 2.1 MPa for a foundation support of 135MPa/m.

## 5. CONCRETE LABORATORY EXPERIMENT

### 5.1 Strength

While the literature provided great insights on what is being done overseas and the risks involved, it does not provide answers for all the challenges faced on the Ben Schoeman freeway. Because the Ben Schoeman contract was expected to run through at least one winter season, special precaution was paid on the gain in strength of the concrete at very low temperatures and on the development of shrinkage cracks.

During design stage a limited laboratory study was done to investigate the capabilities of locally available products. The aim of the study was also to get a better feel of the problem to be experienced on site and to give guidance to biding contractors of what to expect. Major role players in the concrete industry were approached and were given an overview of the project with all the constraints. Seven proprietary mixes from three suppliers were tested at Concrete Testing Services in Johannesburg. The brief was to come up with a durable and workable concrete mix which can gain enough strength within four hours for opening to traffic even in very cold climatic conditions. Initially the target third-point loading flexural strength and compressive strength after four hours were 2.3 MPa (10% higher than minimum of 2.1 MPa mentioned above) and 20 MPa respectively. The results of the experiment are shown in **Table 2**.
It is clear that the strength target was not achievable (in the laboratory) when the samples were cured at a temperature of 0ºC. At 25ºC, six out of seven mixes tested made the specified compressive strength target at 4 hours and could be used. Due to high amount of superplasticizers and other admixtures in the mixes, the flexural strength results tended to be erratic resulting in a generally poor relationship between flexural strength and compressive strengths.

**Table 2: Typical concrete strength results obtained from locally available mixes.**

| Product | Type of Strength | Strength at time t (hrs) @ 25°C | | | | | Strength at time t (hrs) @ 0°C | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | t=4 | t=6 | t=10 | t=14 | t=24 | t=4 | T=6 | t=10 | t=14 | t=24 |
| A | Comp. | 33 | 37.5 | 43 | 44 | 49 | 11.5 | 24.5 | - | - | 37 |
| | Flex. | 4.5 | 4.5 | 2.9 | 3.9 | 3 | 4 | 4 | - | 5.5 | 4.5 |
| B | Comp. | 27.5 | 34.5 | 34 | 33 | 37.5 | 13 | 27.5 | - | 32.5 | 36.3 |
| | Flex. | 2.6 | 3.1 | 3.1 | 3.9 | 3.2 | 2 | 3 | - | 3 | 3.5 |
| C | Comp. | 26.5 | 27.5 | 28 | 34.5 | 37.5 | 5 | 25 | - | 38.5 | 39 |
| | Flex. | 2.7 | 2.2 | 2.3 | 3.3 | 2.8 | 1 | 2.65 | - | 3.5 | 3.6 |
| D | Comp. | 19.5 | 45.5 | 51.5 | 61 | 69.5 | 0 | 0 | 0 | 38.5 | 55.4 |
| | Flex. | 1.8 | 4.3 | 4.7 | 5.3 | 6.2 | 0 | 0 | 0 | 6 | 6.25 |
| E | Comp. | 47.5 | 54 | 68 | 73.5 | 75 | 0 | 0 | 0 | 44.5 | 53.5 |
| | Flex. | 4.5 | 4.7 | 5.2 | 6.8 | 6.7 | 0 | 0 | 0 | 5.25 | 6 |
| F | Comp. | 0 | 0 | 66 | 77.5 | 88 | 13.5 | 15 | 15.5 | 11.5 | 13.5 |
| | Flex. | 0 | 0 | 5.9 | 7.3 | 6.9 | 2.2 | 1.9 | 2.4 | 1.9 | 1.7 |
| G | Comp. | 21.5 | 24 | 21 | 25 | 27.5 | 13.5 | 15.5 | - | 24.5 | 25 |
| | Flex. | 2.7 | 3 | 3.4 | 3.1 | 3.4 | 2.75 | 3 | - | 3.55 | 4.25 |

### 5.2 Shrinkage

At the outset it should be realised that the mechanism of concrete shrinkage is a subject of its own that has already attracted a lot of interest worldwide. There are five different types of shrinkage mechanisms namely, plastic shrinkage, drying shrinkage, autogenous shrinkage, carbonation and thermal shrinkage. It is outside the scope of this paper to discuss them in detail. However, due to the high amount of cement and additives used in these ultra rapid hardening concrete mixes, particular attention was paid to drying and autogenous shrinkage. Plastic shrinkage occurs during the early life of the concrete and can generally be controlled by proper site management (e.g. protecting concrete in cold weather etc) and to a certain extent by the use of an approved curing compound. Drying shrinkage and autogenous shrinkage on the other hand are more difficult to control.

Badenhorst (2003) summarised their mechanisms as follows:

- Drying shrinkage is caused by the evaporation of water from capillary pores in the hardened cement paste. Evaporation takes place if the ends of the capillary pores are exposed to air with a relative humidity lower than that within the capillary system. The process consists of reversible and irreversible components in which water is lost at a decreasing rate.
- Autogenous shrinkage occurs after setting of the concrete and is the consequence of the reaction of the unhydrated cement with the available water in the capillary pores. The volume of the hydration products is less than the volume of the dry cement powder and water. Autogenous shrinkage is relatively small for normal strength concrete but is very significant for concrete with high paste contents such as high-strength and self-compacting concrete.

There are many tests in use around the world to evaluate the shrinkage characteristics of a concrete mix. In South Africa, SABS Method 1085:1994 (amended 2001) is the standard test used to determine the initial drying shrinkage and wetting expansion of concrete. The test however, has been criticised for not simulating actual field performance in many instances. Many research organizations thus opt for a natural drying shrinkage test which is done in conjunction with creep tests. The problem is that the natural drying shrinkage test takes long to complete and is not practical for mix selection and optimization in a conventional project. Thus in this project the SABS Method 1085:2001 was used despite its limitations. The aim was not to evaluate the mixes against the requirement in Committee of Land Transport Officials (COLTO) standard specifications for road and bridge works (max 0.04 %) – which has also been criticised to be quite conservative - but more to evaluate the mixes relatively and to have an indication of the sensitivity of the mixes to shrinkage. The results obtained from all the mixes tested are included in **Table 3**.

**Table 3: Shrinkage (%) results based on SANS 6085/SABS1085:2001**

| PRODUCT | SAMPLE 1 | SAMPLE 2 | SAMPLE 3 | AVERAGE | STANDARD DEVIATION | COEFF OF VARIATION |
|---|---|---|---|---|---|---|
| A | 0.019 | 0.011 | 0.020 | 0.017 | 0.005 | 0.296 |
| B | 0.066 | 0.050 | 0.069 | 0.062 | 0.010 | 0.166 |
| C | 0.022 | 0.007 | 0.039 | 0.023 | 0.016 | 0.706 |
| D | 0.060 | 0.050 | 0.039 | 0.050 | 0.011 | 0.211 |
| E | 0.034 | 0.047 | 0.035 | 0.039 | 0.007 | 0.187 |
| G | 0.036 | 0.058 | 0.058 | 0.051 | 0.013 | 0.251 |

Although some of the products in **Table 3** above have low average shrinkage values their coefficients of variation are outside the limits set by SANS 6085/SABS1085:2001 which requires the range of results to be less than twenty percent of the average for the test to be valid. It is believed that this variation is as a result of sample preparation in the laboratory rather than an inherent variability of the mix.

One has to realise also that the current shrinkage specification of 0.04% is more applicable to plain jointed concrete pavements and not to CRCP or dowelled jointed concrete pavements. Large sections of the N1 freeway south of Johannesburg was built as a plain jointed concrete pavement with andesite aggregate with shrinkage values closer to 0,06% and yet has performed very well.

5.3 Durability

As mentioned earlier, EOT concretes are more heterogeneous and more prone to microcracking. However, the impact of microcracking on long term durability is unknown. Thus, to minimize that risk some of the durability criteria (Alexander *et al*, 1999) used in structural concrete in South Africa was incorporated in the project specification. These included the water sorptivity and the oxygen permeability parameters. These are used to assess the effectiveness of initial curing and the compaction of the concrete respectively. The oxygen permeability is used to quantify the microstructure of the concrete and is sensitive to macro-defects such as voids and cracking.

## 6. APPROVED CONCRETE MIX DESIGN

In addition to the laboratory experiments above, the contractor together with his preferred supplier (Product G) did a battery of tests and trials. In order to further minimize the effect of concrete shrinkage, dolomite from Olifantfontein quarry was selected. Dolomite aggregate has a low water demand as compared to other aggregates which is especially beneficial on the shrinkage properties.

The mix proportion in the approved mix design is summarized in Table 4. Critical criteria of the final approved mix satisfied specified requirements of durability, shrinkage, workability and strength. Due to the many risks and unknowns in this contract, an experimental panel was done in the contractor’s yard prior to the repair of a trial section on the road. These provided practical indicators for the contractor and the engineer to refine the mix, to check the practical application, workability and performance.

**Table 4: Detail of approved concrete mix**

| Mix Proportions | | | |
|---|---|---|---|
| Component | Type | Source | Proportion |
| Cement | PPC Cem1 42.5R | PPC | 507 kg/m$^3$ |
| Admixture | CONTEC QSF | Worldcon (Pty) Ltd | 35 kg per 100 kg of cement |
| Coarse aggregate | 19 mm nominal; Dolomite | Oliefantsfontein | 1263 kg/m$^3$ |
| Fine aggregate | Silica sand | Delmas | 630 kg/m$^3$ |

| Mix properties | | |
|---|---|---|
| Parameter | Approved mix | Specified |
| Water : cement ratio | 0.25 | Max 0.4 |
| Shrinkage (%) | 0.02 | Max 0.04 |
| Compressive strength (MPa) | 20.5 (4 hrs) | Min 20 (4hrs)* |
| Flexural strength(MPa) | 2.2 (4 hrs) | Min 2.3 (4hrs)* |
| Sorptivity (mm//h) | 3.8 | Max 7 |
| Oxygen permeability (log scale) | 10.38 | Min 9.75 |

*The 28-day design strength is as per the standard specification in COLTO (Clause 7103 (d))

## 7. CONSTRUCTION ASPECTS

Once repair areas were identified, they were scanned with ferro scanners to identify the position of steel reinforcement in order to cut marked areas within reinforcement boundaries so as to minimize cutting of further bars in existing concrete 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:

a) Saw cut into panels of 1.5 x 1.2 m. Cutting of heavily reinforced concrete needs specially designed diamond blades.
b) 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.
c) 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 1.2m centre to centre induced cracks 1.2m apart.
d) Scabble all vertical faces.
e) Re-instate all longitudinal main and transverse distribution steel.
f) Prime all vertical faces with concentrate of Contec QSF binder.
g) 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.
h) 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.
i) 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 very good at temperatures less than 18ºc. Aggregates were stored in a cold room at temperature below 18ºc 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 behaviour is very critical and requires constant supervision.

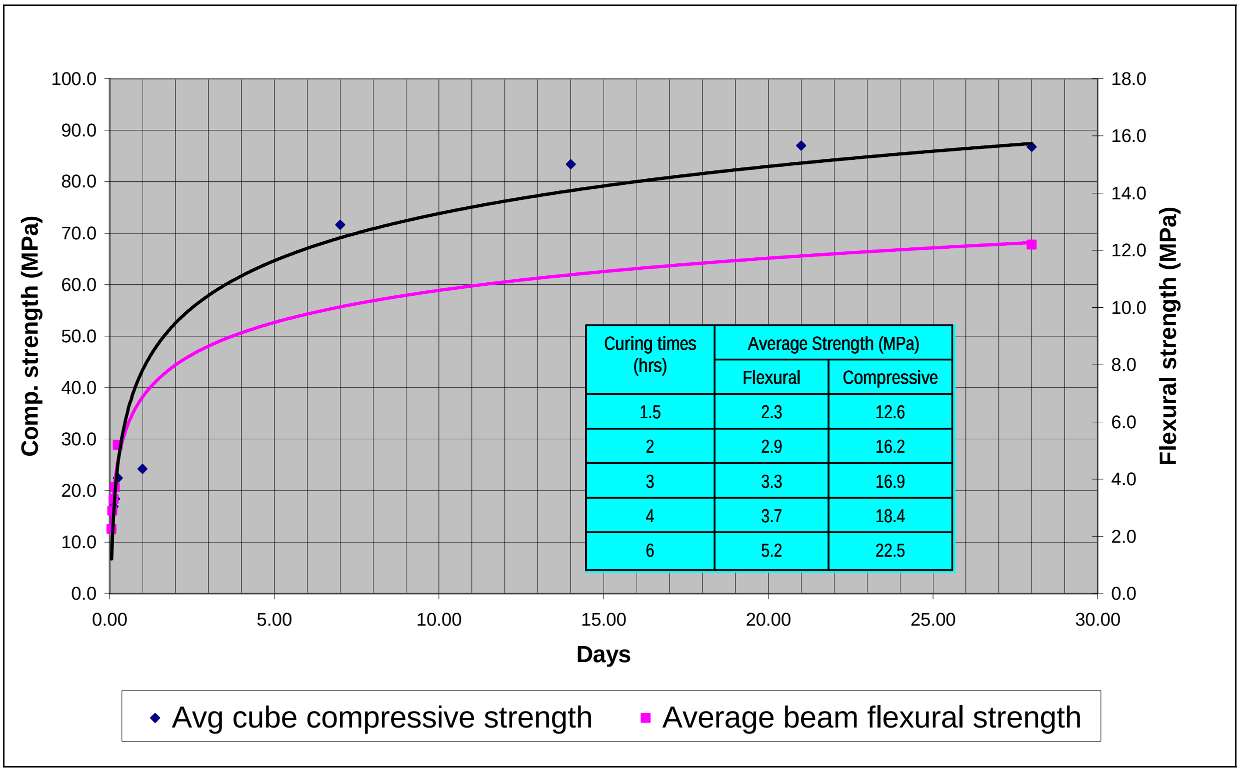
j) Finish off surface texture with soft broom (micro texture) and spring steel tine (macro texture).
k) Curing was done with a resin based curing compound.
l) In very cold weather (night time) a thermal blanket to retain heat is placed over the new concrete.

Some of the construction activities are illustrated in Figure 1. The time window to complete the construction process was from 21:00 hrs to 05:00 hrs. Like any fast-track construction, well-planned construction sequencing was imperative. Apart from the slab saw cutting which was done on the night before, the average duration of the activities was 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

Due to good quality control in the mixing and placing of the concrete, test results were generally good, consistent and within acceptable limits. Average results achieved from production are shown in Figure 2. To date all the patches are performing very well. None one of the patches were damaged from lack of strength at time of opening to traffic (no tyre imprint/shoving or induced cracks). The oldest patch is approximately a year old.


**Figure 1: Typical construction activities**




| Curing times (hrs) | Average Strength (MPa) | |
|---|---|---|
| | Flexural | Compressive |
| 1.5 | 2.3 | 12.6 |
| 2 | 2.9 | 16.2 |
| 3 | 3.3 | 16.9 |
| 4 | 3.7 | 18.4 |
| 6 | 5.2 | 22.5 |

**Figure 2: Average concrete strength obtained**

## 8. CONCLUSIONS AND WAY FORWARD

South Africa is starting to face similar problems facing many road authorities worldwide: the maintenance and renewal of urban freeway pavements. This paper summarises the experience gained on concrete repairs on one of the busiest freeways in Southern Africa. It showed that very early concrete strength can be achieved with the right technology. On average, flexural strength of at least 3,7 MPa was obtained within four hours of placement.

The case study also showed the importance of good integration between the design and construction stages. Meticulous planning of all activities and good relationship between the client, the engineer, the contractor and his suppliers are the other critical elements that contributed to the success of this contract.

Although this concrete repair contract was not a research study, the client was supportive in many ways in making it a case study. However, with the ageing pavement network in South Africa there is a definite need for more research. One of the areas that will require urgent attention is long life pavement rehabilitation strategies (perpetual pavement concepts). Research work is also required on using incentives and penalties driven contracts coupled with lane rentals on very busy freeways. It is foreseen that with the increasing challenges facing the engineer, the contractor will be given more and more financial incentive to participate in reducing the road user cost by working more effectively and efficiently. Active participations from all the role players are a must when dealing with such challenges.

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