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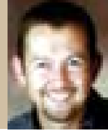
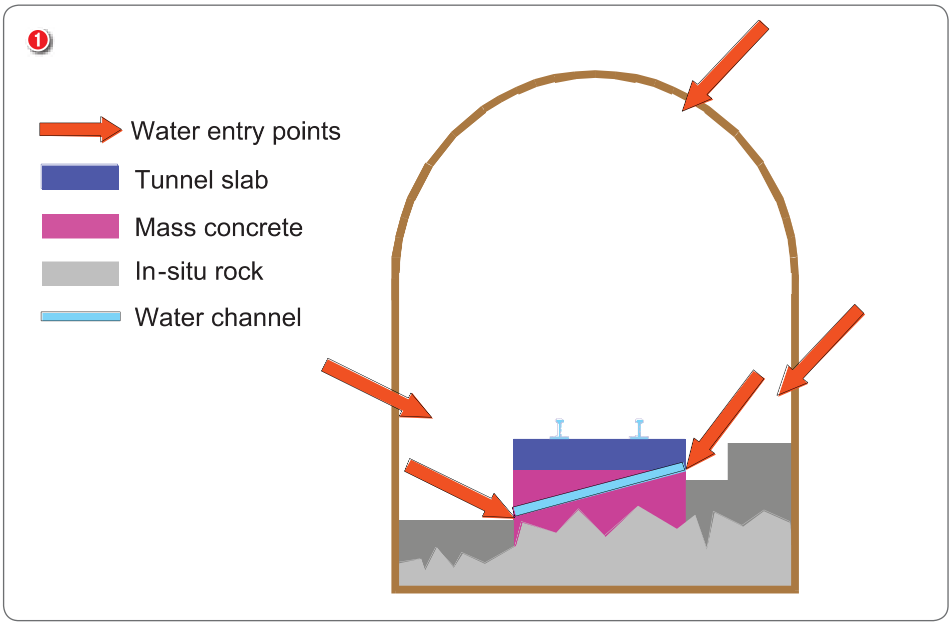


Life after 30!

Innovative investigation and repair of the Overvaal railway tunnel



PROJECT TEAM

Client Spoornet (Coal Line) – Johan Momberg (Project Manager)
Technical advisor Spoornet Track Technology – Hannes Gräbe, Freek Shaw, Ahmed Mulla
Contractor Franki Africa (Pty) Ltd – Chris Wagener

THE 4 KM LONG Overvaal railway tunnel on the Coal Line between Ermelo and Piet Retief was constructed in 1974 by blasting into dolerite of the Ecca Group and Dwyka formation. After serving more than 30 years as the only permanent single line section on the Coal Line, foundation problems dictated the need to investigate and rectify the movement of the tunnel slab and supporting foundation.

THE EARLY YEARS

After blasting, the original tunnel floor was brought to the desired level by casting two to three layers of mass concrete. The track slab, on which the rails are fastened by means of tunnel chairs, was then constructed on top of the mass concrete. The original design entailed a track slab thickness of 300 mm and a slab width of 2 500 mm while the mass concrete varied between 50 mm and 1 500 mm. A large drainage channel was constructed on the left-hand side and a smaller drainage tunnel and walkway on the right-hand side. Drainage pipes which take the water from the right-hand side channel to the larger left-hand side channel were constructed approximately every 100 m.

FIRST SIGNS

More than six years ago, maintenance engineers noticed that the geometry of the track in the tunnel was deteriorating. A pumping action of the slab was also noticed in specific locations. The slab condition deteriorated to such an extent that permanent settlement of the slab (and possibly also the mass concrete) occurred at km 24 in the middle of the tunnel, as well as in a few other locations. At km 24, the cant (superelevation) of the track had to be corrected by the insertion of extra pads and higher chair plates. The chair plate fastenings fatigued as a result of excessive vertical deflection of the slab under train loading and started to fail.

It is estimated that the track settled by approximately 50 mm in the worst location. It was also noticed that water was entering the track foundation through

Figure 1 *Typical cross section of the Overvaal tunnel*
Figure 2 *Water entering the tunnel foundation through openings at the mass concrete drainage channel interface*

Figure 3 The core drilling investigation with three purpose-built trolleys combined to form an investigation 'train'

cracks between the slab and the mass concrete (especially from the shallow drainage channel) and also from the deep drainage channel through cracks in the mass concrete.

PROBING TO THE CORE

During August and September 2005, a core drilling investigation was carried out by Geopractica under the supervision of Protekon (Geotechnical) and Spoornet (Technology Management – Track Technology). Based on the geology and track geometry in the tunnel, some 50 locations for a detailed investigation were identified along the entire length of the tunnel. The frequency of the drilling positions was increased at the problem areas and decreased at locations that appeared to be problem free. This resulted in a drilling location spacing of between 20 m and 150 m.

The investigation entailed the following:

- The drilling of 75 mm cores on the track centre line though the slab, mass concrete and in-situ rock. The aim was to continue drilling up to a maximum depth of 300 mm into the in-situ rock
- Detailed profiling of the cores and the recording of addition information, for example water loss during drilling
- Taking of photographs inside the holes to establish the depth and dimensions of any cracks or voids in the tunnel foundation

Figure 4 *The modified webcam developed to take short-distance pictures inside a 75 mm borehole*
Figure 5 *Typical examples of voids or cracks at the interfaces*
Figure 6 *The three distinctive categories of the mass concrete/in-situ rock interfaces*

- Measurement of the static water table in each drilled hole a week after the drilling was carried out
- Backfilling of the holes with a low-strength grout

CRACKING THE FAILURE MECHANISM

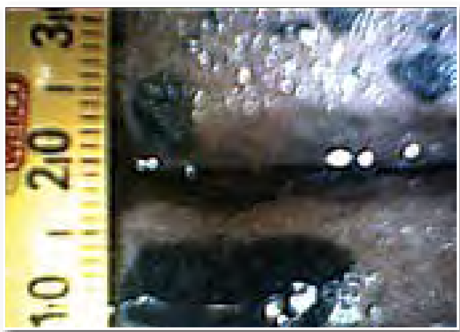
To photograph the inside of the boreholes, a modified webcam was developed. The camera had LEDs grouped around it to illuminate the surface inside the 75 mm borehole.

The core-drilling investigation established the following:

- Cracks or voids were present at the interfaces, namely between the slab and mass concrete, between different layers of mass concrete, and between the mass concrete and in-situ rock
- The occurrence of cracks or voids varied considerably along the length of the tunnel and only short distances of the tunnel had no cracks or voids
- The interface between the mass concrete

(a) Interface between slab and mass concrete – no cracking

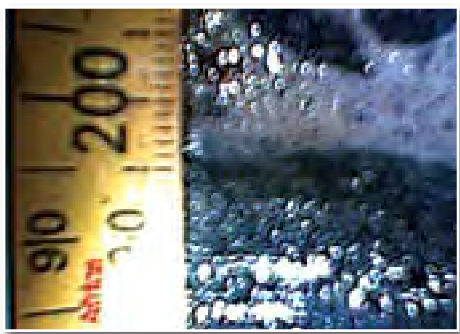
(b) Interface between slab and mass concrete – 2 mm crack



(c) Water flowing through opening between slab and mass concrete

(d) Large cavity in mass concrete

(e) Crack in mass concrete



(f) Undamaged in-situ rock and mass concrete interface

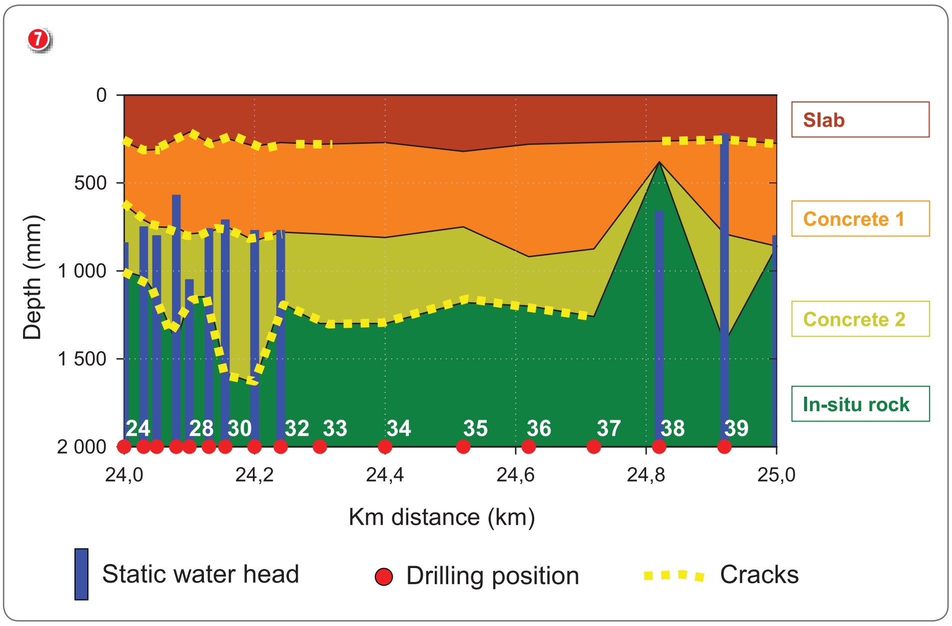


Figure 7 *Example of detailed graph showing core-drilling results (km 24–25)*

and the in-situ rock fell in one of three categories, namely good bond between the mass concrete and in-situ rock with no cracks or voids; the occurrence of loose rock fragments in a saturated clayey silt (possibly through pulverising of the concrete) between the mass concrete and in-situ rock; and the occurrence of loose rock fragments with large water-filled voids between them. The mass concrete penetrated these fragments to a limited depth

The results of the core drilling investigation were used to compile detailed graphs showing the following (see figure 7):

- The testing locations (red dots)
- The dimensions of the tunnel slab, mass concrete and the depth of the in-situ rock (the coloured area plots in the graph)
- The static water table (indicated by the blue bars at each testing location). A completely dry hole is indicated by the absence of a blue bar
- The presence of any cracks or voids at especially the mentioned interfaces (indicated by the yellow dashed lines)

From the core drilling investigation, it was concluded that the cyclic loading, combined with water entering the tunnel foundation through relatively small cracks in the concrete, led to the pumping action of the track slab. Repeated movement resulted in the generation of pore pressures and the gradual growth of the voids at the respective interfaces, thereby slowly pulverising the concrete and washing fines out of the voids. Excessive slab movement caused the tunnel chair component failure, which in turn created severe dynamic impact loading – a vicious circle.

A TENDER APPROACH

Tenders were invited for the permanent repair of the tunnel foundation as described above. The tender was structured as a design and construct solution.

Figure 8 *The epoxy exiting the crack between the tunnel slab and mass concrete*

Wilkit stays in its liquid state while flowing, after which setting takes place with setting times from 10 to 15 minutes. As a result of the fast setting time, no pumping of the epoxy out of the voids took place during the movement of trains over the track. Injection was stopped a few minutes before the arrival of a train and commenced shortly thereafter

The solution was restricted to the repair of the tunnel foundation, which is the track slab, mass concrete and in-situ rock. The following items were included:

- A design and proposed method for the grouting of the void between the slab and the mass concrete: This void was estimated to be between 0,2 mm and 2 mm. The total length of the tunnel that showed this phenomenon was estimated to be approximately 2 000 m
- A design and proposed method for the grouting of the void between different mass concrete layers: This void was estimated to be between 0,2 and 10 mm. The total length of the tunnel that showed this phenomenon was estimated to be approximately 500 m
- A design and proposed method for the grouting of the voids between the mass concrete and in-situ rock: These voids varied considerably in size and were filled with either water or a saturated clayey silt. The total length of the tunnel that showed this phenomenon was estimated to be approximately 1 500 m
- The adjustment of the tunnel slab horizontal alignment at specifically km 24,0 to km 24,25 (250 m) where the slab settled by approximately 50 mm.
- Opening up of the drainage holes in the mass concrete that might have been filled during the grouting/epoxy of the tunnel foundation

During grouting, the contractor had to ensure the following:

- Filling of all voids with a suitable grout or epoxy that matches the dimensions of the specific void
- Precise control over the grouting pressures to ensure that the slab is not lifted higher than required
- Safe working practice while protection from a train perspective was provided by Spoornet

COUNTING THE HOURS

Working time in the tunnel was restricted as this is the only section on the Coal Line where all loaded and empty trains have to run on a single line. A continuous total occupation of roughly 6–8 hours was given on Mondays. In addition to the Monday occupation, short intermittent time slots were allowed between the running of trains.

Preference was given to methods that will allow the track to be opened for traffic as soon as possible after the repair work has been carried out. The required curing periods for the type of grout or epoxy were therefore crucial to the success of the project. The contractor therefore had to design his solution around methods and materials that could be constructed during a limited number of full occupation days as well as short time slots between trains.

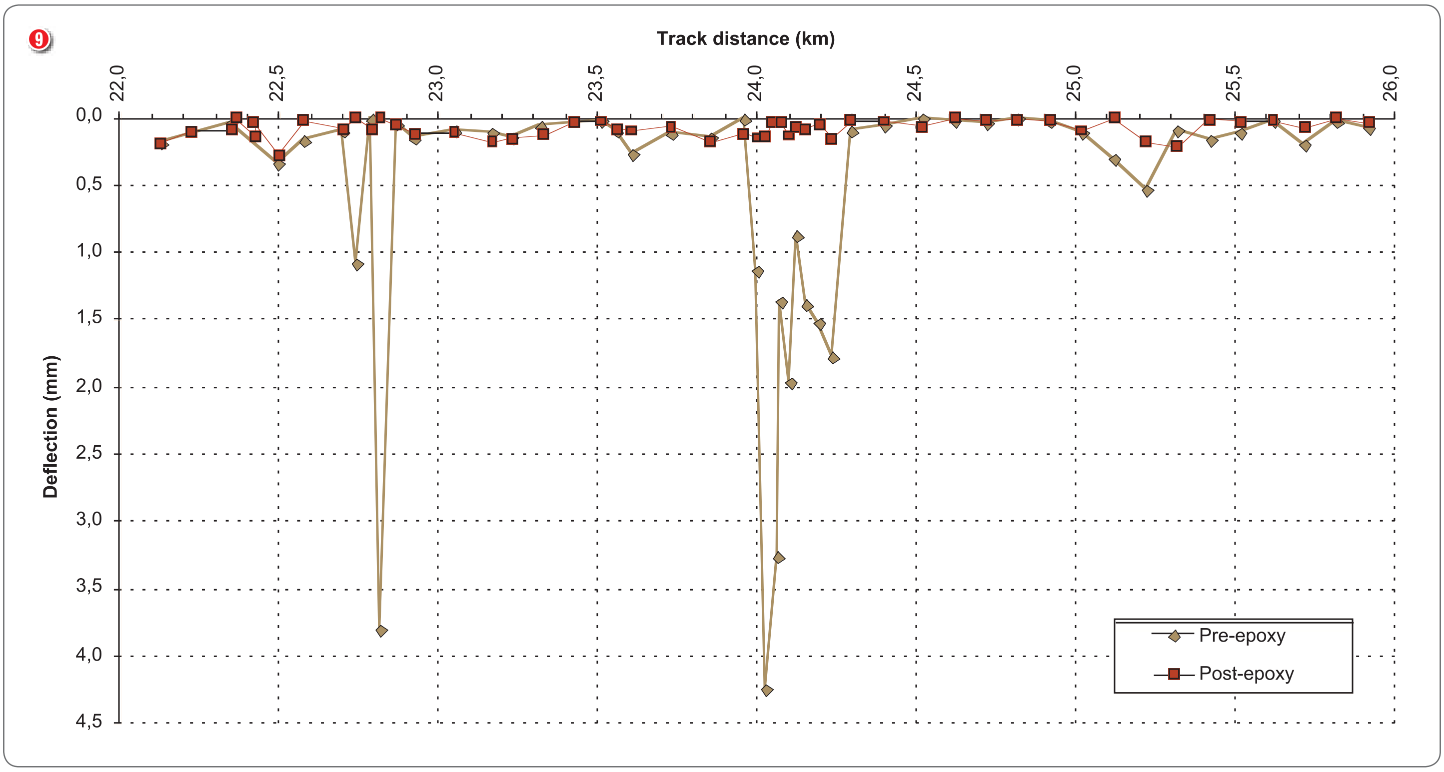


Figure 9 *Deflection measurements under a 26 t axle load vehicle*

Deflection measurements of the track slab were done by using a digital indicator to measure the vertical displacement of the slab under train loading. These measurements were taken before any grouting was done as well as shortly after grouting was completed. Before grouting, maximum deflections of up to 4,3 mm was recorded under 26 t per axle loading. Post-epoxy deflections were limited to 0,2 mm

THE CURE

The successful tenderer (Franki Africa (Pty) Ltd) chose to use a two part Wilkit epoxy system, injected using a toothed wheel or piston pump. The typical strength of the hardened epoxy is in the order of 50 MPa and it is not negatively affected by moisture or temperature. The epoxy could therefore be injected into water-filled cracks, displacing the water and filling all openings. Immediately after mixing, the epoxy begins to harden through a number of chemical processes. Wilkit stays in its liquid state while flowing, after which setting takes place with setting times from 10 to 15 minutes. As a result of the fast setting time, no pumping of the epoxy out of the voids took place during the movement of trains over the track. Injection was stopped a few minutes before the arrival of a train and commenced shortly thereafter.

Excellent penetration of the epoxy into all voids was achieved as evidenced by the appearance of epoxy flowing from the various concrete discontinuities as described earlier. As soon as epoxy emerged, the injection was halted, allowing the epoxy to set. This method blocked the exit points, thereby allowing more epoxy to be injected under high pressure and preventing spillage.

BILL OF HEALTH

The quality of the work was controlled by making use of two tests, namely deflection measurements and water pressure tests.

Deflection measurements of the track slab were done by using a digital indicator to measure the vertical displacement of the slab under train loading. These measurements were taken before any grouting was done as well as shortly after grouting was completed. Before grouting, maximum deflections of up to 4,3 mm was recorded under 26 t per axle loading. Post-epoxy deflections were limited to 0,2 mm. In cases where this was not achieved after the first grouting exercise, re-grouting was required until the maximum deflection of 0,2 mm was achieved. The average post-epoxy deflection of the track slab was 0,08 mm with a standard deviation of 0,07 mm.

Water pressure tests were carried out on the track centre line by measuring the permeability of the foundation in Lugeons. Lugeon is a measure of transmissivity in rocks and is determined by pressurised injection of water through a borehole driven through the rock. One Lugeon (Lu) is equal to one litre of water per minute injected into one metre of borehole at an injection pressure of 10 bars. The permeability of the foundation was limited to 5 Lu in line with international standards for grouting. The average post-epoxy permeability of the track foundation was 0,5 Lu with a standard deviation of 0,7 Lu.

FINAL WORDS

A complete safety evaluation was drawn up for this R10-million project and it was clear from the onset that the intended operation carried a high risk. A safety warning system was therefore implemented to give workers a warning well in advance so that they can remove equipment from the track and move to safe positions in the tunnel. It can be reported that the 20-week construction period was completed incident free.

The dedication of both the client and contractor led to the successful repair of the Overvaal tunnel, thereby ensuring good prospects for life after 30 years!

Acknowledgements

The valuable contribution of the Spoornet Technology Management team is gratefully acknowledged. Freek Shaw developed the borehole investigation camera and Ahmed Mulla was responsible for the quality control measurements. Johan Momberg was the project manager (Spoornet, Coal Line) and Chris Wagener represented the contractor (Franki SA)

Source:
http://www.saice.org.za/downloads/monthly_publications/2007/CivilEngMay2007/#/0