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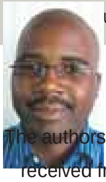

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# Rehabilitation of sinkholes on the N14 near Carletonville

## BACKGROUND

This article showcases Aurecon's involvement in the rehabilitation of a section of the N14 north of Carletonville following the occurrence of a number of sinkholes on the road shoulder that resulted in complete road closure. Three sinkholes formed on the road shoulder at some time between late December 2007 and early January 2008. Two sinkholes (each about 10 m in diameter) formed on either side of a box culvert (see Figure 1), and another on the opposite side of the road (about 4 m in diameter). A 15 km section of the road had to be closed and traffic was diverted along existing roads. Sinkhole rehabilitation and upgrade of the closed section of the N14 is being undertaken under Aurecon's supervision at present. At the time of writing, the rehabilitation work described in this article was in its final stages.

The road is currently under the jurisdiction of the Gauteng Department of Roads and Transport, with the South African Roads Agency (SANRAL) acting as implementing agent on the project.

## PRELIMINARY WORK

The overall objective of the rehabilitation was to implement measures that would, as far as possible, improve the long-term stability of the road. The elements of the work were as follows:

- Sinkhole rehabilitation through dynamic compaction (DC)
- Compaction of the wider area using DC
- Cavity filling through compaction grouting
- Upgrade of the stormwater drainage.

The likelihood for sinkholes to form is determined by the erosion potential of material above dolomite bedrock and by the presence of cavities. Common trigger mechanisms for erosion are poor surface drainage, lowering of the groundwater level, and gravity. The triggers are moderated where a significant thickness of material with low erosion potential occurs above cavities or where cavities occur below the groundwater level.

Figure 1: The two sinkholes that formed on either side of the culvert

A surface reconnaissance in the vicinity of the sinkholes was undertaken, and exploratory drilling was carried out in the sinkhole area. The drilling results confirmed the presence of cavities in the weathered stratum (dolomite residuum) above the groundwater level. None of the above-mentioned mitigating factors are present. Several sinkholes that cannot be attributed to concentrated surface water ingress have occurred in the area, indicating that draw-down of the groundwater level has possibly taken place. Potential trigger mechanisms therefore include surface water ingress (should floods higher than the 1:20 year peak flood occur), lowering of the groundwater level, and gravity. According to the terminology in use, two inherent susceptibility classes (ISCs) occur across the rehabilitation area:

- A medium likelihood for large sinkholes (HSC 4)
- A high likelihood for large sinkholes (HSC 8)

The site dolomite stability conditions considered in the rehabilitation of the site are summarised in Table 1.

The solutions recommended for the rehabilitation work were based on the above assessment, which is borne out by the occurrence of three sinkholes along a short distance of the road (40 m). The DC work and the compaction grouting are described next.

## REHABILITATION

### Dynamic compaction (DC)

Accepted practice (specified in PW 344 – Ref 2) requires that sinkholes are rehabilitated according to the inverted filter method using dynamic compaction (DC). The inverted filter method is designed to prevent future mobilisation of the backfilled material. The use of DC backfilling ensures that people are not exposed to further collapse of the sinkhole during backfilling


Figure 2: Samples per metre for primary borehole P6; the stones represent sections of no sample recovery due to air loss into the formation

and compaction. A 12 tonne pounder was dropped through a height of 18 m on a 5 m grid for primary compaction, and a 5 m grid shifted 2.5 m diagonally, for secondary compaction, followed by ironing blows. The outlines of the sinkholes and the perimeter of the treated area appear in Figure 3.

The intention with dynamic compaction (DC) at the sinkhole area was to rehabilitate sinkholes and to reduce the permeability of near-surface materials.

The depth of penetration using DC was predicted by equation $D=0.5\sqrt{wH}$ (the Menard equation for gravelly soil). With a pounder weight of 12 tonnes, and an 18 m drop height, the equation predicts penetration to 7.3 m. This penetration is affected by the presence of boulders and fine-grained soils. For the project, DC was assumed to have improved conditions to about 5 m depth.

This assumption is contradicted by lost sample – specifically between 2 m and 4 m depth in borehole P6 (Figure 2). The stones in the sample box represent a lack of sample recovery in the borehole drilled for grouting. The failure of DC to compact to any significant depth in this position may be explained by a boulder between 1 m and 2 m depth. Nevertheless, such boulders of chert or dolomite are common in dolomite environments, and must be assumed to be present.

### Compaction grouting – cavity filling

#### Grouting design

The following requirements were considered in the grout design:

- Any voids of more than 5 m in plan dimension had to be filled.
- The spread of grout had to be limited to the footprint area defined for grouting, with the minimum of penetration beyond this area.
- The displacement or erosion of soft formation by grout had to be prevented as far as possible (improvement of in-situ materials was not required).
- The above objectives had to be satisfied with maximum ground heave of 50 mm.

**Table 1 Site dolomite stability conditions**

| Factors | | Assessment | Comment |
|---|---|---|---|
| Subsurface profile characteristics | Erosion potential | Medium to high | Fine sand, chert gravel, residual dolomite |
| | Cavities present | Yes | Proven by sinkholes and boreholes |
| Trigger mechanisms | Surface water | Yes | Flooding possible in the long term. Drainage design allows for 1 in 20 year peak flood |
| | Lowering of groundwater level | Yes | Dewatering sinkholes nearby |
| | Gravity | Yes | – |
| Mitigating factors | Material of low mobilisation potential | No | Absent |
| | Shallow groundwater level | No | Groundwater in dolomite bedrock |

Figure 3: Grout layout

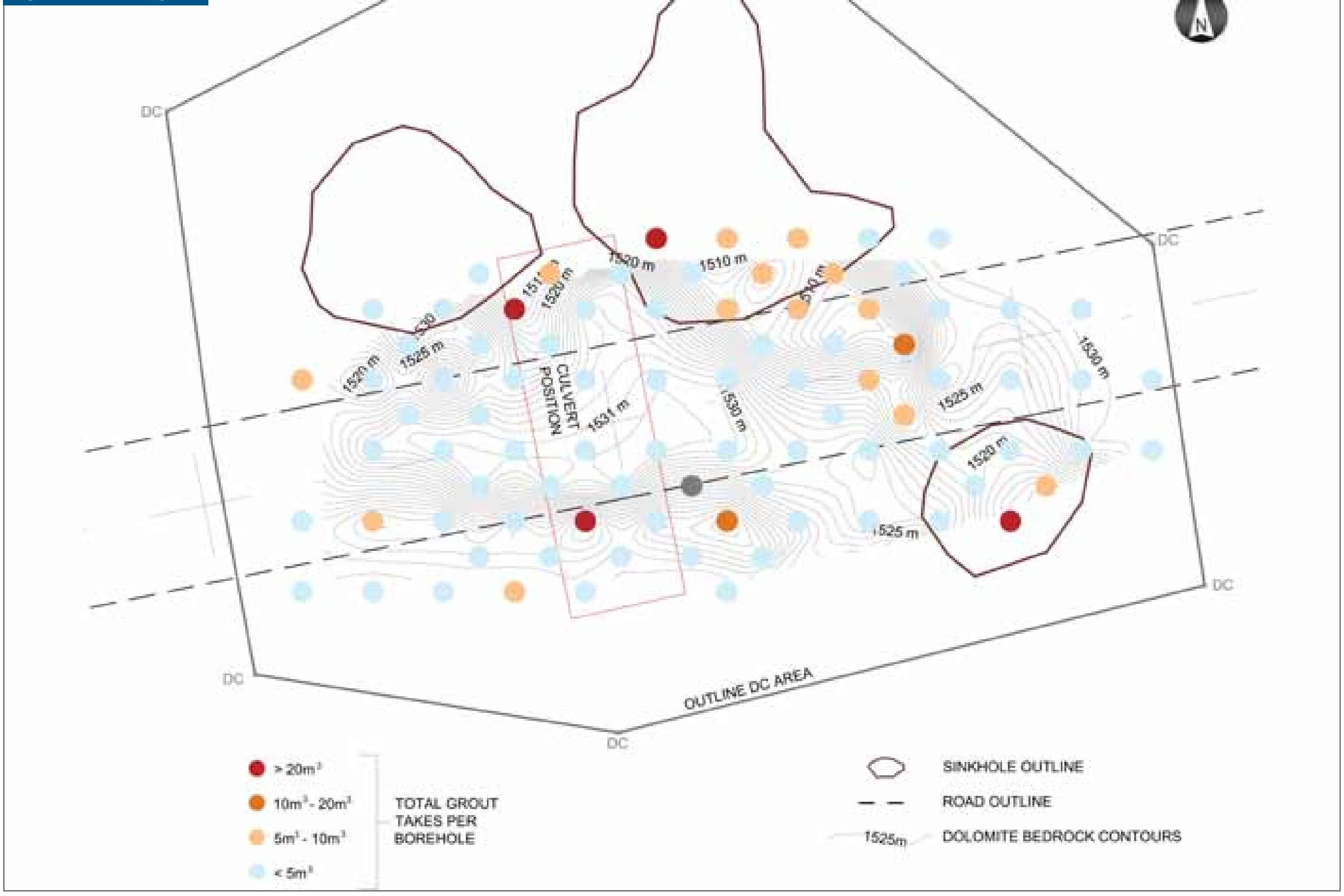


Figure 4: Grouting in progress at the borehole end – in the foreground

Figure 5: Grouting in progress at the pump and monitoring end

The above requirements dictated the grout mix, the grout borehole layout (Figure 3), and the termination criteria.

For the grout mix, a minimum 28-day strength of 2 MPa was required, and mobility had to be limited to a maximum slump of 150 mm (SANS 5862-1-2006). Termination criteria used for the primary boreholes were:

- Maximum 1 bar per level, providing for overburden pressure and head loss through the grout assembly
- Minimum 10 ℓ per metre (borehole volume) and maximum 2 500 ℓ (2.5 m$^3$) per metre.

The criteria were later increased to 2 bar (providing for head loss through the grout assembly, and overburden pressure), and the maximum volume criterion was increased to 5 m$^3$/m. Drilling of grout boreholes was terminated where a continuous depth interval of at least 5 m was interpreted to have intersected dolomite bedrock.

Limitations imposed by budget, available materials and equipment on site required compromises on the constituents and the eventual acceptance criteria. Nevertheless, the eventual product was believed to be satisfactory for the purpose of cavity filling.

The primary borehole grid of 3.4 m by 3.4 m was designed to allow intersection of any cavity equal to or larger than 5 m in plan dimension. Secondary boreholes were inserted on the diagonals of the original grid where significant grout takes occurred in primary boreholes, especially where the maximum volume criteria were achieved at less than the termination pressure. Figures 4 and 5 show the grouting in progress.

#### Grouting outcomes

The total grout area is 525 m$^2$ in extent. With the average depth to bedrock at 18 m, the volume of the grout space is 9 450 m$^3$. Based on the the total grout take to date of 295 m$^3$, the percentage of the grout space that was filled by grout is about 3%. The grout takes are plotted in order of increasing total volume per borehole in Figure 6.

Figure 6 also shows that in about 40% of boreholes, no grout in addition to the assumed actual borehole volume was injected. In another 20% of boreholes, a total of 1 m$^3$ of additional grout was required to fill small cavities along sections of each borehole. Takes of more than 10 m$^3$ occurred in eight boreholes.

Figure 7 shows that significant grout takes were recorded from about 10 m, with the majority of high takes occurring from a depth of about 17 m. It is significant that this level coincides approximately with the average depth to dolomite bedrock (18 m). This reflects the reality that cavities are most common immediately above dolomite bedrock. The flattening at the end of each curve reflects the decrease in grout takes in bedrock. High grout takes per metre occur uninterrupted for an interval of at least 10 m in the boreholes with the highest grout takes.

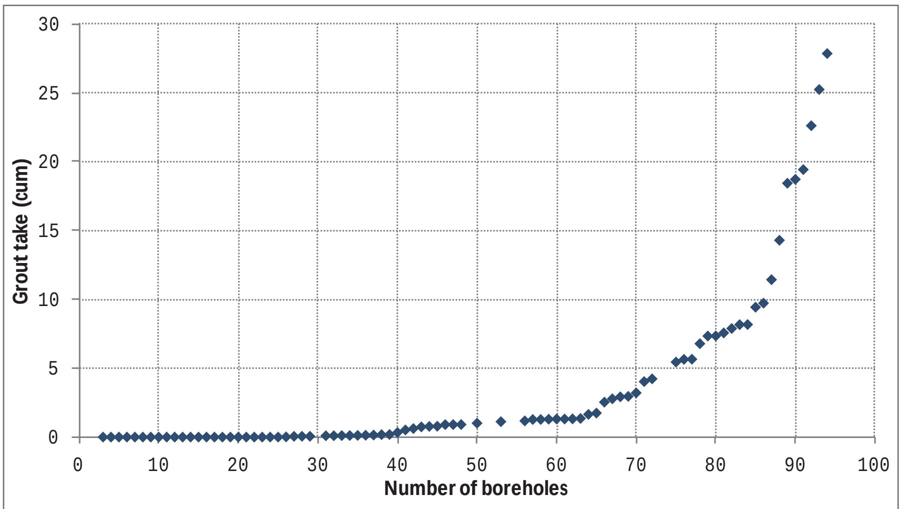


**Figure 6: Grout takes per borehole in order of increasing total volume**

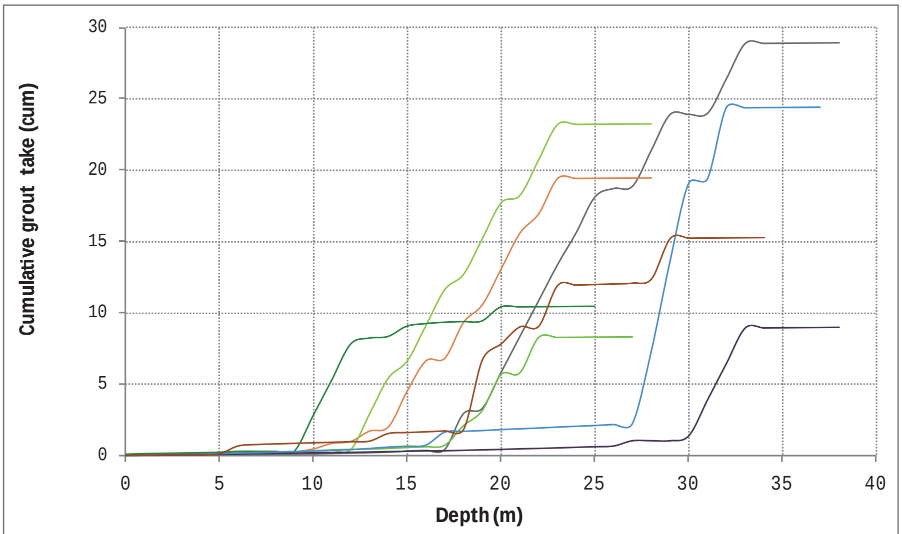


**Figure 7: Cumulative grout take with depth for selected boreholes with total take > 5 m$^3$**

## CONCLUSIONS

The Gautrans–SANRAL-Aurecon collaboration on the rehabilitation has been successful in meeting the rehabilitation challenges with appropriate actions. The actions were as follows:

- Sinkhole backfilling using the inverted filter method and DC
- Compaction of the wider area using DC
- Cavity filling through compaction grouting
- Improved drainage measures.

Drainage provision is a critical element in mitigating the risk of surface water ingress. The area is characterised by very flat-lying topography, and many culverts were observed to be silted up. The drainage design for the sinkhole area includes trapezoidal concrete-lined side drains on both sides of the road, and a concrete inlet structure and spilling basin connecting the culverts with the side drains.

The appropriateness and effectiveness of the other actions are assessed below.

### Dynamic compaction (DC)

The inverted filter principle used in the rehabilitation of sinkholes addresses the assumed mechanism of sinkhole formation. The minimum requirement for backfilling is that workers exposed to the hazard of remobilisation during manual compaction are suspended in harnesses from a secure device. As manual compaction was not practical, given the scale of the rehabilitation work, DC was used. The intervals of lost sample in borehole P6 (Figure 2) suggest that DC does not necessarily consolidate the ground to a significant depth in variable conditions.

The outcome of DC on the treated area outside the sinkholes must be assumed to be limited to reduced permeability.

### Compaction grouting

The assessment that grouting was appropriate for rehabilitation of the sinkhole area was based on the belief that the occurrence of sinkholes on either side of the road in the rehabilitation area indicates the presence of cavities beneath the road surface. Also, the occurrence of three sinkholes on an area as small as 600 m$^2$ in extent was interpreted to confirm numerous underground cavities. The grouting results show that each sinkhole is associated with one borehole where grout takes were greater than 20 m$^3$. In two of these, the high-take boreholes are within the sinkhole outlines, and in the third, immediately outside the outline (Figure 3). A grout take this high was recorded in only one other borehole. The likelihood for cavities underneath the road was also confirmed by high grout takes between the two sinkholes that had formed on opposite sides of the road (Figure 3).

The spacing of the grout boreholes is not small enough to ensure backfilling of every cavity in the grout space. However, the plan locations of boreholes with high grout takes coincide generally with locations of perceived greater instability. It would therefore be reasonable to believe that all of the larger cavities have been backfilled to a significant extent. ◻

Source:
http://www.saice.org.za/downloads/monthly_publications/2013/2013-Civil-Engineering-April/#/0