Subsurface grout barriers for ground stabilization in dolomite areas near Carletonville, South Africa

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Abstract Artificial lowering of the groundwater level in dolomitic aquifers of the Far West Rand gold mining area has led to the formation of hundreds of sinkholes and subsidences. Where ground movements develop in or around important structures, it has become standard practice to drill boreholes for exploration and to inject mine tailings (slimes), cement and water to fill cavernous zones and arrest further ground movements. Although this method of grouting has mostly been effective, some boreholes accepted such large quantities of grout that the operation became prohibitively expensive. This paper describes an experiment to construct subsurface barriers by pouring wet (high slump) concrete via closely-spaced lines of boreholes into cavernous zones beneath a depression on a provincial road. The barriers required a small quantity of concrete and the zone between barriers was quickly filled by grout. The lack of further ground movements confirmed the success of the project.

Keywords Boreholes · Dolomite · Ground stabilization · Mine tailings · Sinkhole

Introduction

Ground surface movements in the form of sinkholes and subsidences have interred 38 people, and caused damage to property in the amount of hundreds of millions of rand (1 rand ≈ US$0.14) in areas underlain by dolomitic rocks in the Gauteng and North-West provinces of South Africa (see Fig. 1) over the past 40 years (Brink 1979; Buttrick and Van Schalkwyk 1995). The most extensive damages have occurred in the Far West Rand gold mining areas around Carletonville, particularly after the groundwater level had been artificially drawn down in order to reduce water flows from the overlying karstic aquifer into gold mine workings at depths of more than 2,000 m below ground surface.

In many instances, the first manifestation of dolomitic instability is ground surface subsidence and the formation of cracks in the walls and floors of buildings and on road pavements. Sinkholes often form where ground subsidence has occurred, but may also develop suddenly and without prior warning. Cracks in buildings and on road surfaces are usually closely monitored, and if movement persists, these structures are evacuated or closed, pending geotechnical investigations and remedial action. Investigations are carried out by means of precise levelling, gravity surveys and rotary percussion drilling, whereas remedial work may involve the filling of subsurface cavities by a mixture of mine tailings (slimes), cement and water.

This paper describes the geology of the dolomitic areas, typical mechanisms of dolomitic instability, previous attempts and problems with respect to the identification (location) and grouting of subsurface cavities, and a new method for limiting the uncontrolled spread and waste of grout materials.

Geology

The geology and geohydrology of the dolomitic areas have been described in detail by Kleywegt and Enslin (1973), Wolmarans (1984) and Eriksson and Altermann (1998). In the Gauteng and North-West provinces, the Chuniespoort Group of the Transvaal Supergroup (age 2300–2200 Ma) is represented by the Oaktree, Monte Christo, Lyttleton and Eccles Formations, which are identified on the basis of the relative abundance of interlayered chert. Although the Monte Christo and Eccles Formations are rich in chert, the other two formations contain chert-poor dolomite. These four units are collectively about 1,430 m thick (South African Committee for Stratigraphy 1980). In some areas, dolomite is overlain by younger deposits belonging to the Pretoria Group of the...
Transvaal Supergroup, the Vryheid Formation of the Karoo Supergroup (Paleozoic age) or unconsolidated sediments of Cenozoic age. A typical stratigraphic column appears in Table 1.

Over geologic times, dolomite rock is dissolved and removed as bicarbonates of calcium and magnesium by weakly acidic rainwater and percolating groundwater. This process is facilitated by fault, fracture and joint networks and results in typical karst features, including interconnected cavities within the dolomite bedrock and a very irregular bedrock surface. Vertical or subvertical solution features predominate within the unsaturated zone, whereas subhorizontal cave systems in the bedrock that usually occur along the present or previous water table elevations represent the main groundwater aquifer. Syenite and diabase dykes of Pilanesberg age (age $\pm 1300$ Ma) that vary in width between 6 and 60 m divide this aquifer into a number of groundwater compartments.

Younger sediments, intrusives or residual materials (weathering products of dolomite and chert) commonly cover the karst landscape and these materials are referred to collectively as dolomitic overburden (Buttrick and Van Schalkwyk 1998). The residual materials within the dolomitic overburden play an important role in the formation of sinkholes and subsidences. They comprise wad (a low-density, fine-grained, black to blue-grey clayey silt or silty clay, which is rich in silica and manganese oxides) or a mixture of wad and chert rubble (collapsed remnants of the chert interbeds). Residual dolomitic soils are commonly very porous, erodible and compressible. These properties are due to leaching, and gaps in grading between wad and chert rubble. Due to natural compaction and ferricrete formation near the ground surface, dolomite profiles are characterized by deteriorating geotechnical characteristics with depth. The upper portions of the soil horizon are often of higher density and strength and relatively impervious.

### Sinkholes and subsidences

The mechanisms of sinkhole formation and the development of subsidences related to groundwater withdrawal in the dolomitic areas of the Far West Rand, have been described by Jennings and others (1965), Brink (1979), Wolmarans (1984) and Buttrick and Van Schalkwyk (1998).

A sinkhole is typically cylindrical or conical in shape and varies in depth (1–50 m) and diameter (1–100 m), whereas the term subsidence refers to a shallow (1–5 m deep) enclosed depression with a long axis up to 1 km in length. A sinkhole is potentially more dangerous than a subsidence in that it usually manifests within a matter of seconds and without prior warning.

The primary requirement for a sinkhole to develop is that parts of the dolomitic overburden are mobilized by gravity and/or water seepage into a receptacle that may be present either as a solution cavity within the bedrock or as disseminated openings within the overburden. If the overburden contains substantial amounts of wad, the potential for mobilization is high. On the other hand, if the overburden comprises dense, impermeable layers of Karoo shale or intrusive sills, the mobilization potential is low. When material is moved from the overburden into a receptacle, a (secondary) void may form within the overburden above the point of exit (throat). This void can grow upwards to form progressively larger arches, until it reaches a more resistant layer, or daylights as a sinkhole. If arching does not develop while material from the blanketing layer is being mobilized, surface subsidence may manifest as the initial stage of sinkhole formation (Buttrick and Van Schalkwyk 1998).

Although some subsidences may represent the initial stage of sinkholes that had not fully developed because of lack of arching, insufficient receptacle space or loss of mobilization, they mostly develop as a result of consoli-