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Managing poorly quantified risks by means of national standards with specific reference to dolomitic ground

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ABSTRACT: The quantification of risk is fundamental to assessing its acceptability. When drafting codes of practice, the quantified risk is used in assessing the reliability of the structure and ensuring this complies with national norms. Problems arise in complex situations where rational determination of risk is difficult. An example is the development of dolomitic land where sinkholes or other forms of subsidence can result in severe damage to the built environment and loss of life. This paper describes the approach currently being adopted in South Africa for the drafting of national standards for the development of dolomitic land and the regulatory processes involved. It also looks at the steps taken to ensure that the standards are not unduly prescriptive.

Keywords: Dolomite, karst, risk management, standards

1 INTRODUCTION

1.1 *Outline of the Problem*

If engineers are capable of erecting buildings that reach 800m into the sky and suspension bridges with main spans just short of 2km, why should we be prohibited from developing on certain categories of dolomitic land? This is the dilemma faced by standards writers when trying to balance the rights of property owners with protection of the general public.

For many years, the South African authorities have discouraged commercial and residential development on dolomitic land where there is a high risk of subsidence. Only agriculture, recreational areas or essential infrastructure have been permitted in such areas. The inclusion of these restrictions in a draft national standard on the development of dolomitic land provoked a reaction from the geotechnical fraternity who questioned the underlying assumption that the hazards cannot be effectively assessed and addressed.

One also needs to question the logic of such a prohibition in the light of some telling statistics. To date, 38 fatalities are known to have been caused by dolomite subsidence events in South Africa (Department of Public Works, 2003). By contrast, the death toll on South Africa's roads for the 2009 calendar year alone was 13 768 (Road Traffic Management Corporation, 2010).

Despite these observations, one must recognize the difficulties that standards writers face when attempting to prescribe ways of ensuring that dolomitic land is developed in a manner that ensures people live and work in a safe environment. This paper looks at the options being considered and debated in South Africa at present to produce a standard that strikes the right balance.

1.2 *Some Background*

Gauteng is the smallest of South Africa's nine provinces, occupying only 1,4% of the area of the country. However, it houses 22% of the country's population and generates 33% of the national gross domestic product. The population density is sixteen times the national average at 660 persons per square kilometre.

Twenty percent of the province's land area is underlain by dolomite of the Malmani Sub-group. Certain of the formations that make up the 1,4km total thickness of dolomite that occurs in the area, particularly the chert rich formations, are prone to the formation of sinkholes and other forms of subsidence related to the dissolution of the dolomites. Some of the country's most densely populated areas, including parts of Pretoria, Soweto, Tembisa and Katlehong are underlain by dolomite. Against this background, the impact of prohibiting development on dolomitic land, or even on certain categories of such land, is self evident.

The two most common forms of dolomitic instability in South Africa are sinkholes and compaction subsidence (previously referred to as dolines). Sinkholes are formed by progressive collapse of the rubble arch above a void or cavity in the underlying residuum or dolomite rock which eventually daylights at the ground surface (Jennings, 1965, Brink 1979 & Wagener, 1982). The most common triggering mechanism is the ingress of surface water. Lowering of the water table also plays a crucial role as the voids which act as receptacles for collapsed material from above are typically present near the level of the original water table. Lowering of the water table exposes these voids and creates the potential for subterranean erosion of the overlying material giving rise to conditions conducive to sinkhole formation.

Compaction subsidences are also related to lowering of the groundwater table. In this case, compressible residuum from the dissolution of the dolomite, typically highly compressible wad, consolidates due to the increase in effective stress caused by lowering the water table, resulting in broad areas of surface subsidence.

Dewatering by the gold mines on the far West Rand during the 1950s and 1960s resulted in the formation of a number of major sinkholes and compaction subsidences, the worst of which was the catastrophic sinkhole which swallowed the West Driefontein Mine Crushing Plant in December 1962 resulting in the loss of twenty nine lives. Although lowering of the water table is now more strictly controlled in many urban areas, the increased potential for surface water ingress as a result of urban development has resulted in a acceleration in the number of sinkholes recorded during recent years. The Council for Geoscience in South Africa has a database of over 2 000 sinkholes, mainly in the Gauteng area.

2 REGULATORY ENVIRONMENT

Table 1 lists the various authorities who control the development of dolomitic land.

Table 1. Role of various authorities

Authority	Role	Guidelines / Standards issued	Comment
Local Authorities	Ensure health and safety of inhabitants within its jurisdiction, including management of geological risks. Approval of development plans.	Various, including dolomite risk management plans if appropriate.	Hampered by lack of skills and funding. Often ineffective.
Department of Public Works (Central Government)	Responsible for infrastructure development.	Appropriate development of infrastructure on dolomite: Manual for Consultants. September 2010.	DPW also involved in drafting of national standards and working groups on dolomite risk management.
Department of Water Affairs (Central Government)	Controls and regulates the water resources of the country including the abstraction of groundwater.	A guideline for the assessment, planning and management of groundwater resources within dolomitic areas in South Africa. Volumes 1 - 3.	Legislation in place but not adequately monitored or enforced.
National Department of Housing (Central Government)	Responsible for controlling and coordinating housing development.	Generic Specification GFSH-2: Geotechnical site investigations for housing development. September 2002.	Also controls the National Home Builders Registration Council.
National Home Builders Registration Council (NHBRC)	Provides a warranty scheme for new housing development. Sets standards and registers home builders.	Home building Manual, Parts 1, 2 and 3. February 1999.	Requires that all houses built on dolomite to have a dolomite stability report which must be submitted to the Council for Geoscience for confirmation that requirements have been met.

Authority	Role	Guidelines / Standards issued	Comment
Engineering Council of South Africa (ECSA)	Setting standards for registration of engineering professional and of professional conduct.	Rules of Conduct for Registered Persons: Engineering Profession Act (Act No. 46 of 2000).	Regards professional registration as a key measure of competence.
Council for Geoscience	Advises government on the judicious and safe use of land. Confirms dolomite stability reports submitted in terms of NHBRC requirements. Custodian of geological and geotechnical information.	Consultants guide: Approach to sites on dolomitic land. November 2007.	Plays a leading role in drafting national standards on dolomite and a controlling role in the approval of housing developments through NHBRC requirements.
South Africa Bureau of Standards (SABS)	Compiles national standards	SANS 1936, Parts 1 – 4. Development on dolomite land. (Currently being re-drafted). SANS 10400, Application of the National Building Regulations.	Redrafting of SANS 1936 being undertaken by a newly formed sub-committee comprising mainly geologists and geotechnical engineers.

By virtue of stipulations by the authorities in Table 1, some aspects of development on dolomitic land are regulated including abstraction of ground water, and the construction of housing and infrastructure. Although the guidelines issued by the Council for Geoscience specify permissible types of development and development densities for various dolomite hazard classes, the Council has no regulatory authority of its own except when it acts on behalf of the NHBRC or Department of Public Works in confirming the acceptability of dolomite stability assessments. In reality, commercial development is also regulated in that plans have to be approved by the Local Authority who may have their own guidelines in place or refer to the Council for Geoscience. Industrial and mining developments on dolomite are currently not regulated.

In South Africa, National Standards are not mandatory, they are merely statements of good practice. This changes when a standard is incorporated into legislation, for example by virtue of the National Building Regulations and Building Standards Act (Act 103 of 1977). This Act makes allowance for compliance with the Regulations either directly or by virtue of "deemed-to-satisfy" rules laid down in the various parts of SANS 10400. SANS 1936, the proposed national standard for development of dolomite land, will be referenced in deemed-to-satisfy provisions of SANS 10400 once it is finalised. It is not, however, listed as a compulsory standard at present.

3 HAZARD ASSESSMENT AND CLASSIFICATION OF DOLOMITIC LAND

3.1 *Buttrick's scenario of supposition method*

Over the years, a number of methods of assessing the risk of dolomitic instability have been proposed. These included identification of lineations using aerial photo interpretation, steep gravity gradients, local zones of thicker overburden and anomalies on infrared thermal imagery (Day & Wagener, 1984). Many of these were developed for specific geological conditions and were not applicable across the country.

In 1992, Buttrick proposed the use of the "scenario supposition method" which provided a framework for the evaluation of dolomitic stability. This was later developed into a proposal for dolomite land hazard and risk assessment (Buttrick et al, 2001).

Using this method, the stability of an undeveloped parcel of land is viewed in the context of a scenario where either the water table is static or the water table could be drawn down in the future. The method requires a hypothesis on the probable impact of man's activity which could include ground water abstraction or the introduction of surface water into the profile. The applicable scenario provides the framework within which the evaluation procedure can be applied.

The evaluation procedure is based on establishing whether or not the soil profile on the site exhibits inherent conditions that contribute to the formation of sinkholes or subsidences. The method also strives to obtain an indication of the likely maximum size of a sinkhole. Table 2 summarises the factors that are considered in the evaluation process.

In the application of this method, the assumed scenario and the mobilization potential of the blanketing material are the key factors in determining the likelihood of a sinkhole or subsidence occurring. The potential development space is the key factor in assessing the likely size of such features.

Table 2. Factors that influence the development of sinkholes and subsidences

Factor	Brief Explanation
Receptacle development	The formation of a sinkhole requires a receptacle to receive the mobilized material from the overlying profile. Such receptacles may either be disseminated voids or interconnecting openings in the overburden or substantial cavities or caves in the bedrock. Unless there is compelling evidence to the contrary, it is assumed that most dolomitic profiles contain such openings even if not encountered during site exploration.
Mobilising agency	Typically the mobilizing agency is ingress of water or drawdown of the table. It is generally assumed that water ingress will occur to some extent during the life of the development.
Nature and mobilization potential of blanketing layer	The blanketing layer includes all strata that overlie the potential receptacles. The susceptibility of this material to consolidation and subsurface erosion should be assessed considering aspects such as grading, consistency, cohesion, permeability and cementing. The mobilization potential of the materials in this blanketing layer determines the risk that, in the presence of a mobilizing agency, subsidence will occur. Low risk profiles are those with a shallow water table, that include stable horizons (e.g. shales or intrusive sills) or exhibit a general absence of voids. On the other hand, the presence of voids, air/sample loss during drilling, a deep water table and erodible material all indicate a high risk of mobilization.
Potential development space	The potential development space provides an estimate of the potential size of a sinkhole. It is determined primarily by the depth of receptacles and the angle of draw of the various strata overlying these receptacles. Angles of draw may vary from 45° for chert rubble to 90° (vertical sides) for shales or intrusive horizons.
Lateral extent	This factor plays a role particularly in the formation of compaction subsidences where the lateral extent of potentially compressible material is an influencing factor.

3.2 *Proposed classification*

Using the conclusions from the scenario of supposition method, the inherent hazard class for each area of the site is determined based on the likelihood of the inherent hazard (sinkhole or subsidence) occurring in the absence of any special preventative measures and the potential size of the sinkhole. The categories used in the definition of these two parameters are given in Tables 3 and 4 respectively. These parameters may then be used to determine an inherent hazard class as shown in Table 5.

Table 3. Inherent hazard categories

Inherent Hazard	Expected events per hectare per 20 years*	Equivalent return period on one hectare
Low	<0.1	>200 years
Medium	0,1 – 1,0	20 – 200 years
High	>1,0	<20 years
	* In the absence of any special precautions	

Table 4. Sinkhole size categories

Maximum diameter at surface	Size
<2m	Small
2m – 5m	Medium
5m – 15m	Large
>15m	Very large

Table 5. Definition of inherent hazard classes

Inherent Hazard Class	Inherent hazard for given size of sinkhole				Risk of subsidence (doline)	
	Small	Medium	Large	Very large	No dewatering	Dewatered
1	Low	Low	Low	Low	Low	Low
2	Med	Low	Low	Low	Med	-
3	Med	Med	Low	Low	Med	-
4	Med	Med	Med	Med	Med	-
5	High	Low	Low	Low	High	-
6	High	High	Low	Low	High	-
7	High	High	High	Low	High	
8	High	High	High	High	Low-high	Low-high

4 DEVELOPMENT OF A PERFORMANCE BASED STANDARD FOR DOLOMITIC LAND

Watermeyer et al (2008) described a four level performance based regulatory system which has formed the basis for the development of a national standard on the development of dolomite land (SANS1936).

Level 1 is a broad statement of the objective or goal of the regulatory system. The stated objective of SANS 1936 is to provide for the development of dolomite land in a manner that ensures that people live and work in a safe environment, damage to or loss of assets is within limits acceptable to society and the cost effective and sustainable use of land.

Level 2 states the functional requirements in qualitative terms. In SANS1936 this is that land underlain by dolomite shall present an acceptable risk of sinkhole and subsidence formation over time.

Level 3 is the establishment of quantitative performance requirements to give effect to the functional requirement defined in Level 2. Based on the work of Buttrick et al (2001), SANS1936 defines the tolerable hazard as one where the number of events (sinkholes or subsidences) that occur is less than 0,1 events per hectare per 20 years. The code then prescribes the permissible type and density of development and the mitigating measures to be put in place in order to achieve the tolerable hazard level.

Level 4 specifies the method of compliance with the performance requirements. In SANS1936 this is achieved by stipulating that development of dolomite land is to be undertaken under the control of a competent person and by laying down requirements for the investigation of dolomitic land, the design and inspection of precautionary measures and the development of dolomite risk management strategies.

5 PROBLEM AREAS

Although the above framework for the development of a performance based national standard appears reasonably straightforward, there are differences of opinion with regard to the detailed requirements of the draft standard. These differences of opinion have centred on the three key issues discussed below.

5.1 *Prescription of hazard evaluation methods*

The original draft of the code effectively prescribed the use of the scenario supposition method for the assessment of inherent hazard classes. While the method is regarded as a major step forward and can readily be applied for routine evaluation of inherent hazards on dolomitic land, its interpretation remains subjective and its application relies on a number of assumptions. Its entrenchment in the code stifles initiatives in the quest for other rational methods of hazard assessment.

The viability of using alternative approaches was demonstrated during the investigation for the Gautrain, Gauteng's new high speed railway. In this instance, a statistical analysis of the size and distribution of sinkholes in the area was undertaken to arrive at a rational assessment of the hazard.

The working group responsible for drafting the amendments to SANS 1936-2 proposes to keep the scenario supposition approach as a deemed-to-satisfy method of hazard assessment but, in addition, to allow alternative approaches based on rational analysis.

5.2 *Prohibition of development*

In defining the precautionary measures required to reduce the inherent hazard to a tolerable level, four categories of mitigating measures (D1 to D4) were introduced. In the case of the highest category, D4, the early versions of the code stated "no precautionary measures can reduce the dolomite risk to acceptable levels". This statement gave rise to the debate encapsulated in the rhetorical question posed in the introduction to this paper. It effectively stifles the development of designs or construction methods which specifically address and effectively mitigate the particular hazards on the site. The possibility of alternatives to this approach was illustrated by the innovative solutions adopted for the construction of the Gautrain which, of necessity, crosses significant tracks of dolomite land on the southern outskirts of Pretoria including those with some of the highest possible inherent hazard ratings. In this case, teams of local and international engineers came up with appropriate design solutions which included ground reinforcement, compaction grouting, dynamic compaction, preloading, stiffened track slabs and the use of large diameter shafts extending well into competent bedrock at depths of up to 70m for the founding of viaducts.

To address this issue and make allowance for properly engineered solutions, the current working group has proposed five requirements for the D4 dolomite area designation.

These are that:
- investigation, design, specification, supervision and formulation of risk management requirements be undertaken by a competence level 4 geo-professional (see below);
- the design, precautionary measures and risk management plan should specifically address and mitigate the risks present on site;
- the proposals be reviewed by a similarly qualified professional;
- the local authority review the proposals and appoint an independent reviewer if required; and
- that the local authority commit to maintain the necessary dolomite risk management principals.

5.3 *Definition of a competent person*

The definition of competent person in the early versions of the code contained very stringent requirements for experience in specific fields, to the extent that only a handful of persons would qualify. This definition provoked a response from many areas of the engineering and geological community. The Engineering Council of South Africa lodged a formal objection with the Bureau of Standards insisting that the only criteria should be professional registration and possession of the necessary experience.

As a compromise, the definition of competent person was amended to "a person who is qualified by virtue of experience, qualification, training and in-depth conceptual knowledge of development on dolomitic land".

With the proposed removal of the blanket prohibition on the development of certain dolomitic land and the introduction of peer review, the working group felt the need for defining levels of competence for specialised aspects of the work. Fortuitously, the Engineering Council also recognised that certain categories of structural and geotechnical engineering work should be undertaken only by persons with an appropriate level of competence and embarked on the compilation of codes of practice for geotechnical and structural engineering. These codes include definitions of competence levels 1 to 4 which correspond to candidate professionals, registered professionals, experienced professionals and expert professionals. The "gates" that permit from one level to the next are tertiary education, professional registration, experience and recognition by the profession respectively. The proposal is very similar to that proposed by the ICE's Site Investigations Steering Group (1993). As these codes of practice have not yet been published, the working group have proposed that a definition of competent levels similar to that adopted by the Engineering Council be included as a normative annex to the code.

6 CONCLUSION

The use of a performance based standard with clearly stated objectives has provided a solution to the difficulties involved in writing codes intended to deal with poorly quantified risks. Ongoing debate and refinement of the code has resulted in a proposal to remove the restrictive provisions contained in the earlier draft as this will open the door to innovative approaches to dealing with the problem in the future.

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