Guidelines for urban engineering geological investigations in South Africa

J.L. van Rooy · J.S. Stiff

Abstract These guidelines endeavour to provide a standard by which engineering geological investigations for urban development should be carried out. The investigations for urban development can be divided into three different categories, namely: investigations for planning, investigations for urban development and specialized geotechnical investigations. The minimum requirements for the planning and urban development investigations are listed. These guidelines suggest the level at which the various types of investigation should be carried out as well as the range of application, the scope and the methodology to be used for the different investigations. It is hoped they will provide guidance to both practitioners and clients on the importance and application of engineering geology in the establishment of new urban development.

Résumé Dans cet article sont présentées des lignes directrices pour la réalisation de travaux géologiques et géotechniques concernant l'aménagement urbain. Trois catégories d'études différentes peuvent être distinguées: études géologiques de planification, études géologiques de développement urbain, études géotechniques spéciales. Les exigences minimum concernant les études de planification et de développement urbain sont présentées. Ces lignes directrices définissent le niveau devant être atteint par ces études ainsi que leur champ d'application et les méthodes devant être mises en oeuvre. On espère qu'elles constitueront un guide à la fois pour les praticiens et pour les commanditaires tout en attirant leur attention sur l'importance des études de géologie de l'ingénieur pour les travaux de développement urbain.

Keywords Urban · Site investigations · Engineering geological mapping

Mots clés Aménagement urbain · Études de site · Cartographie géotechnique

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Introduction

Since the first democratic government in South Africa was elected in April 1994 a so-called Reconstruction and Development Programme (RDP) was set in motion to address some of the problems of the apartheid era. This RDP is an integrated, coherent socio-economic policy framework that seeks to mobilise all the people and the country's resources to build a democratic, non-racial and non-sexist future. It has been drawn up by the African National Congress (ANC)-led alliance in consultation with other key mass organisations and with assistance from a wide range of non-governmental and research organisations (African National Congress 1994).

Among its five key programmes is that of meeting basic needs, an essential part of which is clearly the provision of housing, drinking water and sanitation. The housing backlog is such that vast areas of land are needed for the construction of houses. Due to the rapid urbanisation of the recent past, most of the best land suitable for development in close proximity to urban centres has been exhausted. Geologically safe sites have to be found and investigated before private and governmental agencies are prepared to finance such projects. It is stated in the Development Facilitation Act (DFA) of 1995 that laws should ensure the safe utilisation of land by taking factors such as geological formations and hazardous undermined areas into consideration. The sustained protection of the environment should also be promoted.

Some of the regulations of the DFA state that the land development applicant must include in his or her application an initial geotechnical assessment. Two other guideline and code of practice documents were published in support of the DFA and its regulations: the Code of Practice for Foundations and Superstructures for Single Storey Residential Buildings of Masonry Construction, which was published through a joint effort of the South African Institution of Civil Engineers and the Institute of Structural Engineers (1995) and the National Home Builders Registration Council's Standards and Guidelines document (NHBRC 1995). These documents list typical founding materials with expected soil movement for each material type and suggested foundation designs and building procedures for each class of structure. These proposed foundation solutions are reflected as construction requirements.
Geotechnical constraints on urban development should therefore be identified and understood so that: (1) the constraints are considered at an early stage in the planning and design of urban areas; (2) the impact of urban development on the environment can be better understood and provided for; and (3) non-renewable resources such as building sands and brick-making clays are not misused by such development.

Historical background

The first legislation in which geotechnical aspects of land development were addressed was the Transvaal Provincial Ordinance 25 of 1965 (Province of Transvaal 1965). Regulation 24(b) of this Ordinance stipulates that the Townships Board must report on the "suitability of the site with respect to the area, position, water supply, soil, aspect, contours, danger of flooding, the presence of dolomite rock (karst), possibility of extension, grade of streets, accessibility and any other circumstances that may affect the proposal to establish a township".
The karst stability aspect and recommendations regarding geotechnical investigations for urban expansion have been referred to the Geological Survey of South Africa (presently the Council for Geoscience). The geological report has to zone the proposed area earmarked for development into zones suitable for different types of land-uses, e.g. special residential, general residential, industrial, sport and recreation and unsuitable for development. The final decision on township layout rests with the Director of Local Government, with his recommendations incorporated in the conditions for township establishment.
This 1965 Ordinance was replaced in 1986 with the Transvaal Provincial Ordinance 15, which came into effect on 10 June 1987. It applies to all township applications submitted since that date. It was intended "to consolidate and amend the laws relating to town-planning and the establishment of townships; and to provide for matters incidental thereto". Regulation 18(1) states "an application for the establishment of a township in terms of Section 69 or 96 of the Ordinance shall be accompanied by ... (b) a detailed report with comprehensive motivation relating to ... (ii) the design and end use of the erven (land parcels) and streets in the township with special reference to ... (cc) how the township will be affected by ... (bbb) geotechnical conditions ...".
The Less Formal Townships Establishment Act no. 113 (1991) came into effect on 1 September 1992. This act was specifically introduced to try to speed up the process of land provision for townships for less formal forms of residential settlement and to regulate the residential settlement of communities in tribal lands. According to Schedule 2(2) of this act, "every application shall, at the time it is lodged with the Administrator, be accompanied by ... (1) a copy of a geotechnical report ...".
The Development Facilitation Act no. 67 (1995) came into effect on 28 September 1995 and has already been referred to above. Regulations specifically related to the required geotechnical assessment appear in Section 26 of Government Gazette no. 17395 of 30 August 1996 (Development Facilitation Act 1996). The following sub-sections are important:

1. The land development applicant shall include in his or her application, as set out in Annexure B, an initial geotechnical assessment.
2. The designated officer shall make a recommendation to the tribunal as to whether a comprehensive geotechnical report should be prepared.
3. The tribunal may, on the basis of the initial geotechnical assessment, impose an appropriate condition of establishment as contemplated in Section 32(2) or 51(2) of the Act; or require the land development applicant to prepare a comprehensive geotechnical report.
4. The costs of both the initial and comprehensive report shall be borne by the applicant.
5. The initial report shall indicate, on the basis of a desk study, excluding field work and utilizing information from maps, databank sources and, where relevant, interpretation of aerial photographs, the suitability of the proposed site for the planned development by reference to the following factors:
   (a) whether the site is underlain by dolomitic rocks, and, if so, shall generally evaluate the risk of sinkhole and compaction subsidence (doline formation);
   (b) whether the site is undermined, and, if so, the depth, geometry, etc. of the workings, and if affected by undermining, the risk of mining subsidence shall be generally assessed;
   (c) whether the site is located on clays which will shrink and swell in response to changes in soil moisture, and, if so, the probable heave movement;
   (d) whether the site is located on soils with a collapse of grain structure, and, if so, the probable magnitude of the settlement that could occur should these soils be saturated under load;
   (e) the occurrence of seep areas and drainage channels;
   (f) the position of the 1:50-year flood line;
   (g) the occurrence of existing perched (and possibly future perched) and normal water tables;

(h) whether there is existing or future slope instability on the natural ground surface;

(i) the suitability of the local materials for the construction of, and construction on, earthworks;

(j) the depth to which the profile can probably be excavated with a backhoe;

(k) the permeability of the soils and their performance in the transport of waste water;

(l) the occurrence of areas of outcrop and sub-outcrop and their effect on excavation;

(m) whether structures will require modification/reinforcement and/or special foundations.

The Development Facilitation Act (1995) is the first Act to standardize the geotechnical investigation procedures throughout South Africa. The Ordinances discussed above applied specifically to the former Transvaal Province, which was made up of the present Gauteng Province and parts of the Northern, North-West and Mpumalanga Provinces. The tribunals referred to in the regulations are established in terms of the Act in the provinces and have the power to make decisions and to resolve conflicts in respect of land development projects.

In response to the above Acts and regulations, a resolution was passed at the 4th Symposium on Terrain Evaluation and Data Storage, Midrand (1994), to formalise the methodology of engineering geological site investigations for township establishment. A sub-committee was formed to devise guidelines for engineering geological/geotechnical investigations for urban expansion. The "Guidelines for Urban Engineering Geological Investigations" published jointly by the South African Institute of Engineering Geologists and the South African Institution of Civil Engineers (SAIEG and SAICE 1997) is the first response from the geotechnical professions to meet the requirements of the DFA.

Due to the previous legislation in the old Transvaal Province, certain guidelines were already in place, which were applied in the Transvaal. The primary concern of the Transvaal Provincial authorities was obviously the negative impact of surface movements in the dolomitic areas, especially where mining activities resulted in the lowering of the groundwater levels in the Far West Rand. The Orange Free State Province introduced a very similar Ordinance at a later stage and these legislative measures resulted in a three-phased approach in geotechnical investigations for township establishment:

Phase 1: A reconnaissance survey, comprising typically a desk study and a walk-over survey.

Phase 2: Detailed planning investigations, often used for township-layout planning; similar to the reconnaissance survey, with a higher level of detail, including soil profiling and sampling. *This phase's scope has often been exceeded and used without qualification for the design of structures.*

Phase 3: Design investigations for specific uses of a particular site. These investigations are detailed and tailored to the type of development intended.

In an attempt to better define the above investigation classes an informal working committee was established which resolved to classify terrain into three soil zones on the basis of their suitability for housing development:

Soil Zone I: Normal residential development can take place without any further precautions.

Soil Zone II: Development can take place provided certain precautionary measures are taken as prescribed.

Soil Zone III: Conditions are such that individual investigations for an erf (building plot for a house) or a structure are required and prescribed standard precautions are to be taken.

This phased approach has lead to some confusion as: not all projects systematically commence at Phase 1 and progress to completion at Phase 3; the extent and detail of each phase has never been clearly defined; the limits of the accuracy of detail have not been clearly understood by clients; and a lack of framework within which to prepare cost estimates for projects has led to unfair competition between consulting firms and organisations.

Unfortunately, there was never a specific guideline document published by the professional bodies and the above approach was only followed in one or two of the earlier provinces. The SAIEG and SAICE (1997) document fills this gap and provides a reference for consultants, clients and decision-makers on the guidelines for evaluation of land for urban development from a country-wide perspective.

The historic events that led to a number of catastrophic sinkholes and dolines on dolomite land, especially in the Far West Rand where the mines de-watered large areas, meant that a reaction from the geological and geotechnical professions was required in order that the problems could be dealt with in a specific way. Much research and practical experimentation was carried out and a technical committee was set up to deal with surface stability investigations on land underlain by dolomitic bedrock. The investigation of the stability of dolomite areas for urban development is therefore excluded from the guideline; the evaluation of conditions associated with such areas can be regarded as specialised investigations, dedicated specifically to characterising the stability of each site. The present state of the art is described by Buttrick and Van Schalkwyk (1995) and the proposed approach is the culmination of many years of specific work carried out in this field. The investigation of near-surface soil horizons in these areas will, however, typically follow the procedure described in the guidelines by SAIEG and SAICE (1997).

The approach and general guidelines proposed in the document are discussed in some detail below.

Categories of urban engineering geological investigation

An investigation can pass through a number of stages on its path to completion. It begins with the gathering of general information and becomes more detailed in successive steps. The classification of a satellite image down to the detailed analysis of an auger hole for the placement of a single pile serves to illustrate the range of detail and extent of an investigation. Each investigation type is unique and the extent and detail of work to be performed is clearly specified to minimise the likelihood of a misunderstanding occurring between consultant and client.

Geotechnical/engineering geological investigations are divided into three categories: (1) planning – providing information for town and regional planners and decision-makers involved in urban development; (2) development – providing information to developers of urban areas; and (3) specialised investigations – detailed investigations of complex sites or the investigation of sites for which specific engineering design parameters need to be determined. Table 1 provides a summary of the types of investigations that are necessary. Only the first two types are described with details on the tasks associated with each type. The specialised geotechnical investigations are not dealt with in the guideline.

In all the investigation types described, the "Guidelines for Soil and Rock Logging (1994)" compiled by the AEG (South African Section), SAIEG and the Geotechnical Division of SAICE (AEG et al. 1994) must serve as the standard by which soil and rock profiles are described and presented. Investigations should only be carried out by engineering geologists who are professionally registered geological scientists (Pr. Sci. Nat.) or geotechnical engineers who are professionally registered engineers (Pr. Eng.).

Engineering geological investigations for urban planning

Investigations of this nature provide the broadest level of detail on the geotechnical conditions of a site. This is the first step in evaluating a particular area for housing development, whether it is regional engineering geological mapping (REGM) or a feasibility study for development of a particular site where REGM has not already been done. The purpose is to provide a broad overview of the suitability of the land for the proposed development and to outline obvious constraints to the development of that area.

Engineering geological information at this level is kept in databanks at the Council for Geoscience and by other mapping and research institutions such as the CSIR. Copies of geotechnical reports pertaining to specific township investigations within certain municipalities and other local government jurisdiction areas are usually available at city, municipal and provincial councils. It is important to contact these institutions before commencing a site inves-

Table 1
Categories of urban geotechnical investigation

Type	Planning investigations		Urban development investigations		Specialised investigations
Description	Regional engineering geological mapping (REGM)	Mapping for urban planning	Urban development investigation	Urban development investigation	Specialised geotechnical investigation
Size of study area	More than 1,000 ha	Less than 1,000 ha	Less than 10 ha	More than 10 ha	Not relevant
Field work	Walk-over survey and limited test pits and soil sampling	Walk-over survey	Test pits, trial holes and soil sampling	Walk-over survey with trial pits and test holes and soil sampling	Specific to type of specialised investigation
Suggested number of test pits	A minimum of 3 test pits per land facet type	None suggested. However, a limited number of test pits may be required at discretion of consultant	Between 6 and 10 test pits[a]	Between 1 and 6 test pits per 10 ha depending on size and variability of area to as much as 1 test pit per hectare for highly variable sites[a]	Dependent on type of specialised investigation performed
Mapping unit	Land systems and land facets	Terrain types: 1 – most favourable, 2 – intermediate, 3 – least favourable	Soil classes: C, H, S and P and other (e.g. excavation, drainage features)	Soil classes: C, H, S and P and other (e.g. excavation, drainage features)	Not applicable
Reference	Brink et al. (1982)	Partridge et al. (1993)	Code of Practice: Foundations and Superstructures	Code of Practice: Foundations and Superstructures	Not relevant
Consultants	Engineering geologists	Engineering geologists and to a lesser extent geotechnical engineers	Both engineering geologists and geotechnical engineers	Both engineering geologists and geotechnical engineers	Geotechnical engineers and to a lesser extent engineering geologists

[a] Note that these figures are not intended to be absolute and should serve only as a guideline

Table 2
Geotechnical classification for urban development. (After Partridge et al. 1993)

Constraint		Most favourable (1)	Intermediate (2)	Least favourable (3)
A	Collapsible soil	Any collapsible horizon or consecutive horizons totalling a depth of less than 750 mm in thickness[a]	Any collapsible horizon or consecutive horizons with a depth of more than 750 mm in thickness	A least favourable situation for this constraint does not occur
B	Seepage	Permanent or perched water table more than 1.5 m below ground surface	Permanent or perched water table less than 1.5 m below ground surface	Swamps and marshes
C	Active soil	Low soil-heave potential predicted[a]	Moderate soil heave potential predicted	High soil-heave potential predicted
D	Highly compressible soil	Low soil compressibility expected[a]	Moderate soil compressibility expected	High soil compressibility expected
E	Erodability of soil	Low	Intermediate	High
F	Difficulty of excavation to 1.5 m depth	Scattered or occasional boulders less than 10% of total volume[a]	Rock or hardpan pedocretes between 10 and 40% of total volume	Rock or hardpan pedocretes more than 40% of total volume
G	Undermined ground	Undermining at a depth greater than 100 m below surface (except where total extraction mining has not occurred)	Old undermined areas to a depth of 100 m below surface where stope closure has ceased	Mining within less than 100 m of surface or where total extraction mining has taken place
H	Instability in areas of soluble rock	Possibly unstable	Probably unstable	Known sinkholes and dolines
I	Steep slopes	Between 2 and 6 degrees (all regions)	Slopes between 6 and 18 degrees and less than 2 degrees (Natal and Western Cape)	More than 18 degrees (Natal and Western Cape)
			Slopes between 6 and 12 degrees and less than 2 degrees (all other regions)	More than 12 degrees (all other regions)
J	Areas of unstable natural slopes	Low risk	Intermediate risk	High risk (especially in areas subject to seismic activity)
K	Areas subject to seismic activity	10% probability of an event less than 100 cm/s^2 within 50 years	Mining-induced seismic activity more than 100 cm/s^2	Natural seismic activity more than 100 cm/s^2
L	Areas subject to flooding	A "most favourable" situation for this constraint does not occur	Areas adjacent to a known drainage channel or floodplain with slope less than 1%	Areas within a known drainage channel or floodplain

[a] These areas are designated as 1A, 1C, 1D or 1F where localised occurrences of the constraint may arise

tigation to ensure that duplicate investigations of an area do not take place.

Results of urban engineering geological investigations should be reported in a simple and understandable format for the benefit of those not familiar with the technical terms of the earth and engineering sciences. In order to facilitate this, the "Geotechnical classification for township development" of Partridge et al. (1993) is recommended as a technical standard by which the suitability for development should be indicated. According to this approach, terrain types are identified by allocating an alphanumeric code to the mapped unit. The categories of suitability for development (most suitable, intermediate and least suitable) are designated numbers 1 to 3 and the geotechnical constraints A to L (Table 2). For example, an area categorised as 3CL is an area underlain by clay soils with high heave potential and which falls within a drainage channel or flood plain.

The information gained at this level of investigation does not provide adequate detail to enable the design and construction of housing and bulk infrastructure and must be augmented by further, more detailed investigations. This category of investigation is divided into two types on the basis of the size of the study area.

Regional engineering geological mapping exercises

An REGM exercise is a vital first step in the planning of urban development. The guideline document proposes this type of investigation for large areas, typically greater than 1,000 ha, such as vacant land around urban and metropolitan centres. REGM exercises facilitate the following: (1) the planning of future development axes of urban areas; (2) assessment of the natural resources of areas earmarked for future development, to reserve and prevent the sterilisation of these resources; (3) identification of geological constraints at an early stage in the planned development; and (4) the provision of information for an environmental impact assessment of urban development, which will assist in identifying ecologically sensitive areas.

Procedure of investigation

The following is the procedure typically followed in regional engineering geological investigations of a large area. The investigation is always initiated with a desk study to obtain all relevant physical information pertaining to the site. This should include, where available, geological and topographic maps, air photographs (preferably of a scale greater than 1:30,000), orthophotographs, agricultural soil maps, geohydrological maps or data and any relevant information from previous work in adjacent areas. Any information considered relevant to the investigation, such as geophysical surveys of the area, should also be included.

An air-photo interpretation of available aerial photography to identify terrain units is undertaken. Air-photo interpretation considers the land form (geomorphology), vegetation and tone/textural variations in the identification of mapping units. These terrain units, combined with the parent geology, define the terrain mapping unit. Any other physical features, natural or man-made, that are likely to have an impact on the development of the area must also be indicated.

Owing to the extent of the area mapped, it is not cost-effective to sample every terrain mapping unit identified; hence it is necessary to sort, as far as possible, these terrain mapping units into groups with similar properties (analogues). In the definition of Brink et al. (1982) these analogues are called land facets and are areas of similar land form, soil profile and groundwater condition. These land facets are further grouped into land systems, which are particular associations of land facets and can be observed as distinct patterns of terrain.

A minimum total of three soil profiles with representative soil tests per analogue identified is suggested. Generalised profiles and material properties are derived and from these the land facets are classified according to categories of geotechnical constraint as listed in Table 2. A map is produced indicating the different development suitability classes for the area investigated.

Potential resources for construction materials must also be indicated. If requested, sites most suitable for cemeteries and waste-disposal should be identified. Finally, a report is produced describing the study area and presenting the maps generated, soil profiles logged and the results of soil tests.

Mapping for urban planning

Typically this type of investigation is required for an area less than 1,000 ha in size, for which urban development is planned. If an REGM exercise has been carried out, this should be used to evaluate the feasibility of utilising the area for urban development. However, in areas where no such information is available, an urban-planning investigation is necessary to evaluate the feasibility of developing the area and this will serve as the first step in the land-evaluation process.

Procedure of investigation

A desk study and air-photo interpretation is carried out as described for the REGM investigation. The site is again classified into the terrain mapping units. A compulsory walk-over survey of the whole site follows to verify the observations made, noting additional information that is relevant for the proposed use of the site. Where appropriate, the site visit should include an examination of the condition of existing structures in the vicinity and also record the vegetation on the site. In areas where desk-study information is scarce a limited number of test pits and soil tests will be required to characterise the terrain adequately. The use of a dynamic cone penetrometer (DCP) as a cost-effective means of gaining an indication of the consistency of the soils on site is recommended (Brink et al. 1982). The DCP is particularly useful when the penetrometer's results can be calibrated against soil profile logs from the site.

A map with the terrain mapping units and the different development suitability classes for the area investigated is produced accompanied by a report with soil profiles, laboratory test results and a description of the study area. Potential resources for construction materials and, if requested, sites suitable for cemeteries and waste disposal should be indicated.

Investigations for urban development

The purpose of these investigations is to determine and map the detailed engineering geological and geotechnical conditions of the terrain in order to delineate and define areas of geotechnical constraint. From this information a design and cost estimates for the proposed development can be provided. The procedure of investigation as described for the undermentioned urban development investigation for sites smaller than 10 ha aims to provide a standard framework with which all investigations of terrain for urban development must conform to achieve an acceptable level of accuracy.

These investigations also supplement the Code of Practice: Foundations and Superstructures for Single Storey Residential Buildings of Masonry Construction which was published by The Joint Structural Division of SAICE and Institution of Structural Engineers (1995). According to the code of practice document, the purpose of the code is to provide:

- classification of founding horizons according to their potential to cause foundation movements;
- general design principles to accommodate expected foundation movements;
- guidance on the location and design of articulated joints;
- rules relating to the structural aspects of superstructures of such buildings; and
- an indication of ease of construction on founding horizons exhibiting a low range of movement.

Tables 3–6 summarise the residential site class designations and foundation design, building procedures and precautionary measures as presented in the code of practice document. The minimum requirement of urban devel-

Table 3
Residential site class designations (SAICE 1995)

Typical foundation material	Character of founding material	Expected range of total soil movements (mm)	Assumed differential movement (% of total)	Site class
Rock (excluding mud rocks which exhibit swelling to some depth)	Stable	Negligible	–	R
Fine-grained soils with moderate to very high plasticity (clays, silty clays, clayey silts and sandy clays)	Expansive soils	<7.5	50%	H
		7.5–15	50%	H1
		15–30	50%	H2
		>30	50%	H3
Silty sands, sands, sandy and gravelly soils	Compressible and potentially collapsible soils	<5.0	75%	C
		5.0–10	75%	C1
		>10	75%	C2
Fine-grained soils (clayey silts and clayey sands of low plasticity), sands, sandy and gravelly soils	Compressible soil	<10	50%	S
		10–20	50%	S1
		>20	50%	S2
Contaminated soils Controlled fill Dolomitic areas Land fill Marshy areas Mine waste fill Mining subsidence Reclaimed areas Very soft silt/silty clays Uncontrolled fill	Variable	Variable		P

1. Classifications C,H,R and S are not intended for dolomitic area sites unless specific investigations are carried out to assess stability (risk of sinkholes and doline formation) of dolomites. Where this risk is found to be acceptable, the site shall be designated as Class P (dolomitic areas).
2. Site classes are based on assumption that differential movements, experienced by single-storey residential buildings, expressed as a percentage of total soil movements are equal to about 50% for soils that exhibit expansive or compressive characteristics and 75% for soils that exhibit both compressible and collapse characteristics. Where this assumption is incorrect or inappropriate, total soil movements must be adjusted so that resultant different movement implied by the table is equal to that which is expected in the field.
3. In some instances, it may be more appropriate to use a composite description to describe a site more fully e.g. C1/H2 or S1 and/or H2. Composite Site Classes may lead to higher differential movements and result in design solutions appropriate to a higher range of differential movement e.g. a Class R/S1 site. Alternatively, a further site investigation may be necessary since the final design solution may depend on the location of the building on a particular site.
4. Where it is not possible to provide a single site designation and a composite description is inappropriate, sites may be given multiple descriptions to indicate range of possible conditions e.g. H-H1-H2 or C1-C2.
5. Soft silts and clays usually exhibit high consolidation and low bearing characteristics. Structures founded on these horizons may experience high settlements and such sites should be designated as Class S1 or S2 as relevant and appropriate.
6. Sites containing contaminated soils include those associated with reclaimed mine land, land down-slope of mine tailings and old land fills.
7. Where a site is designated as Class P, full particulars relating to founding conditions on site must be provided.
8. Where sites are designated as being Class P, reason for such classification shall be placed in brackets immediately after suffix i.e. P(contaminated soils). Under certain circumstances, composite description may be more appropriate, e.g. P(dolomite areas)-C1.
9. Certain fills may contain contaminates which present a health risk. The nature of such fill should be evaluated and should be clearly demarcated as such.

opment investigations is to provide the necessary geotechnical parameters to enable the site to be classified according to the stipulations in the code of practice. Sufficient information should be supplied for the design of single-storey residential structures and infrastructure services related to urban development.
Urban development investigations are subdivided into two types, based on the size of the area considered, as the approach and execution of engineering geological and geotechnical investigations of small areas differ significantly from those of larger areas.

Urban development investigation sites smaller than 10 ha

This type of investigation is carried out to enable classification of the site in terms of the recommended foundation solutions and building procedures set out in the SAICE Code of Practice (1995). Examples of this type of investigation are: (1) investigations of subdivided erven, plots or stands for housing development; (2) investigations for applications for re-zoning of erven, plots or stands; and (3)

Table 4
Foundation design, building procedures and precautionary measures for single-storey residential buildings founded on expansive soil horizons (SAICE 1995)

Site class	Estimated total heave (mm)	Construction type	Foundation design and building procedures (expected damage limited to Category 1)
H		Normal	Normal constructional (strip footing or slab-on-the-ground foundations) Site drainage and service/plumbing precautions recommended
H1	7.5–15	Modified normal	Lightly reinforced strip footings Articulation joints at all internal/external doors and openings Light reinforcement in masonry Site drainage and plumbing/service precautions
		Soil raft	Remove all or part of expansive horizon to 1.0 m beyond perimeter of structure and replace with inert backfill, compacted to 93% MOD AASHTO density at –1 to +2% of optimum moisture content Normal construction with lightly reinforced strip footings and light reinforcement in masonry if residual movements are <7.5 mm, or construction type appropriate to residual movements Site drainage and plumbing/service precautions
H2	15–30	Stiffened or cellular raft	Stiffened or cellular raft with articulation joints or lightly reinforced masonry Site drainage and plumbing/service precautions
		Piled construction	Piled foundations with suspended floor slabs with or without ground beams Site drainage and plumbing/service precautions
		Split construction	Combination of reinforced brickwork/block work and full movement joints Suspended floors of fabric-reinforced ground slabs acting independently from structure Site drainage and plumbing/service precautions
		Soil raft	As for H1
H3	>30	Stiffened or cellular raft	As for H2
		Piled construction	As for H2
		Soil raft	As for H1

1. Differential heave is assumed to equal 50% of total heave.
2. Relaxation of some of these requirements, e.g. reduction or omission of steel or articulation joints, may result in a Category 2 level of expected damage.

the investigation of small vacant lots within previously investigated or already developed areas.

Procedure of investigation

The limited size of the area warrants only a limited desk study to obtain any relevant information pertaining to the site. This should include any broad-level information that is easily obtained, such as information from geological and topographic maps, agricultural soil maps and any previous work done in the area. The number of test pits that are excavated will depend on the variability of the conditions on the site and hence will vary considerably from one geological environment to another. The guideline document recommends between six and ten test pits as 1 day's fieldwork will usually suffice for the evaluation of these areas. This must not be considered as absolute or restrictive; a higher density of sampling points will be required in more complex situations.
The soil profile should be described using the method and terms as initially proposed by Jennings et al. (1973) and which are now incorporated in the "Guidelines for Soil and Rock Logging" (AEG et al. 1994). Note must be made of the geohydrological character of the site and in particular the presence of perched or permanent groundwater levels. The use of a dynamic cone penetrometer (DCP) as a cost-effective means of augmenting soil profile data is also recommended (Brink et al. 1982).
A minimum of three samples of each potentially problematic soil horizon should be taken. Typical index tests should include at least foundation indicator properties (grading analysis, Atterberg limits and linear shrinkage) and optionally CBR or Mod AASHTO if necessary for urban road design. Other tests can also be performed at the discretion of the engineering geologist/geotechnical engineer or depending on the intended use of the site; these would typically include, swell potential, collapse potential and consolidation tests.
The report prepared should be accompanied by a map demarcating the ground conditions into zones according to SAICE's Code of Practice (1995). All relevant additional site conditions, including shallow bedrock, drainage paths, perched water tables, problem soils, possible slope instability, previous land uses (i.e. landfill site), undermining and the presence of potential construction materials, must be reported.
The involvement of the engineering geologist or geotechnical engineer should ideally extend into the development stage of the project with a follow-up visit to the site at the early stages of construction. This is to ensure that there is correct implementation of the recommendations proposed in the report and that appropriate actions are taken should unforeseen site conditions arise or be exposed during the early stages of construction.

Table 5
Foundation design, building procedures and precautionary measures for single-storey residential buildings founded on horizons subject to both consolidation and collapse settlement (SAICE 1995)

Site class	Estimated total settlement (mm)	Construction type	Foundation design and building procedures (expected damage limited to Category 1)
C		Normal	Normal construction (strip footing or slab-on-the ground foundations) Good site drainage
C1	5–10	Modified normal	Reinforced strip footings Articulation joints at some internal and all external doors Light reinforcement in masonry Site drainage and service/plumbing precautions Foundation pressure not to exceed 50 kPa
		Compaction of in-situ soils below individual footings	Remove in-situ material below foundations to a depth and width of 1.5 times foundation width or to a competent horizon and replace with material compacted to 93% MOD AASHTO density at −1 to +2% of optimum moisture content Normal construction with lightly reinforced strip foundation and light reinforcement in masonry
		Deep strip foundations	Normal construction with drainage requirements Founding on a competent horizon below the problem horizon
		Soil raft	Remove in-situ material to 1.0 m beyond perimeter of building to a depth of 1.5 times widest foundation or to a competent horizon and replace with material compacted to 93% MOD AASHTO density at −1 to +2% of optimum moisture contact Normal construction with lightly reinforced strip footings and light reinforcement in masonry
C2	>10	Stiffened strip footings, stiffened or cellular raft	Stiffened strip footing or stiffened or cellular raft with articulation joints or solid lightly reinforced masonry Bearing pressure not to exceed to 50 kPa Fabric pressure not to exceed to 50 kPa Site drainage and service/plumbing precautions
		Deep strip foundations	As for C1 but with fabric reinforcement in floor slabs
		Compaction of in-situ soils below individual footings.	As for C1
		Piled or pier foundations.	Reinforced concrete ground beams or solid slabs on piled or pier foundations Ground slabs with fabric reinforcement Good site drainage
		Soil raft	As for C1

1. Differential settlement is assumed to equal 75% of total settlement.
2. Relaxation of some of these requirements, e.g. reduction or omission of steel or articulation joints, may result in a Category 2 level of expected damage.

Urban development investigation sites larger than 10 ha

This type of investigation is carried out in areas larger than 10 ha in size. The classification of the site in terms of the recommended foundation solutions and building procedures set out in the SAICE Code of Practice (1995) is to be followed as for the previous investigation stages. Examples of this type of investigation are: (1) investigations of sites for housing development; and (2) investigations for applications for erven, plot or stand re-zonings.
The different site classes with the recommended foundation solutions and building procedures are presented as Tables 3–6 (after SAICE and Institute of Structural Engineers 1995).

Procedure of investigation

If available, the relevant "Investigation for Urban Planning" report must be obtained as this will provide the necessary background information to the site, facilitating rapid and efficient planning of the investigation (i.e. in positioning test pits). If this report is not available, the procedure listed for a mapping for urban planning investigation will constitute the first stage of this investigation.
A number of factors will influence the density of test pits required to characterise the investigated area adequately. Some of these are: the variability of the bedrock geology; the variability of the terrain morphology; and size of the area being investigated.
These factors will vary considerably between geographical regions in the country and areas of differing extent for which investigations are being requested. A typical range of one to six test pits per 10 ha is suggested as a guide for most sites. Higher densities (up to one test pit per hectare) may be warranted in areas where the geology and topography are known to be highly variable. The values suggested in the guidelines should be seen as only a guide within which to operate and the number of test pits proposed for the evaluation of the site should be determined in terms of the above-mentioned factors.

Table 6
Foundation design, building procedures and precautionary measures for single-storey residential building founded on horizon subject to consolidation settlement (SAICE 1995)

Site class	Estimated total settlement (mm)	Construction type	Foundation design and building procedures (expected damage limited to Category 1)
S	10	Normal	Normal construction (strip footing or slab-on-the-ground foundations) Good site drainage
S1	10–20	Modified normal	Reinforced strip footings Articulation joints at some internal and all external doors Light reinforcement in masonry Site drainage and service/plumbing precautions Foundation pressure not to exceed 50 kPa
		Compaction of in-situ soils below individual footings	Remove in-situ material below foundations to a depth and width of 1.5 times foundation width or to a competent horizon and replace with material compacted to 93% MOD AASHTO density at –1 to +2% of optimum moisture content Normal construction with lightly reinforced strip foundations and light reinforcement in masonry
		Deep strip foundation	Normal construction with drainage requirements Founding on a competent horizon below problem horizon
		Soil raft	Remove in-situ material to 1.0 m beyond perimeter of building to a depth of 1.5 times widest foundation or to a competent horizon and replace with material compacted to 93% MOD AASHTO density at –1 to +2% of optimum moisture content Normal construction with lightly reinforced strip footings and light reinforcement in masonry
S2	>20	Stiffened strip footings, stiffened or cellular raft	Stiffened strip footing or stiffened or cellular raft with articulation joints or solid lightly reinforced masonry Bearing pressure not to exceed to 50 kPa. Fabric reinforcement in floor slabs Site drainage and service/plumbing precautions
		Deep strip foundations	As for S1 but with fabric reinforcement in floor slabs
		Compaction of in-situ soils below individual footings	As for S1
		Piled or pier foundations	Reinforced concrete ground beams or solid slabs on piled or pier foundations Ground slabs with fabric reinforcement Good site drainage
		Soil raft	As for S1

1. Differential settlement is assumed to equal 50% of total settlement.
2. Relaxation of some of these requirements, e.g. reduction or omission of steel or articulation joints, may result in a Category 2 level of expected damage.
3. Account must be taken on sloping sites since differential fill heights may lead to greater differential settlements.
4. Settlements induced by loads imposed by deep filling beneath surface beds may necessitate adoption of a construction type appropriate to a more severe site class.

The following factors/steps in the site investigation correspond to those described for sites smaller than 10 ha:
- the geohydrological character of the site;
- use of a dynamic cone penetrometer (DCP);
- sampling and testing of potentially problematic soil horizons;
- reporting on soil tests, soil profiles, rock outcrop, areas of poor excavation, drainage paths, perched water tables, problem soils, possible slope instability, previous land uses (i.e. landfill sites), undermining, and the presence of potential construction materials; and
- a map demarcating the ground conditions into zones according to the SAIEG/SAICE (1997) guidelines and the SAICE Code of Practice (1995).

The involvement of the engineering geologist or geotechnical engineer in the development stage of the project is again stressed.

Specialised geotechnical site investigations

These investigations are more specialised and detailed in nature. Although they are mentioned in the guidelines, they are excluded from consideration as the methodology for most of these specialised investigations is well documented elsewhere. Examples of such investigations are geotechnical site investigations for civil engineering construction, environmental engineering evaluations for waste disposal and cemetery site investigation, dolomite stability investigations and investigations of contaminated land. Pollution by industrial effluents or byproducts includes both organic and inorganic contamination. Radon gas emissions associated with the radioactive decay of residues found in mine tailings are a serious health hazard and therefore reclaimed mine dumps must be evaluated prior to their use for urban development and particularly housing.

Summary

The urgent need for safe housing sites in present-day South Africa has forced the professional bodies in the engineering geological and geotechnical fields to set standards for site investigations for urban expansion. The "Guidelines for Urban Engineering Geological Investigations" (SAIEG and SAICE 1997) are the first attempt to guide specifically urban site investigations. The guideline document proposes the subdivision of urban engineering geological investigations into urban planning, urban development and specialised types of investigations. It sets out what is considered good practice by engineering and geological professionals in investigations and evaluations of terrain for urban development. Suggestions are made as to the level at which the various types of investigation should be applied, providing guidance to practitioner and client alike on the range of application, scope and methodology of the various types of investigation.
The "Guidelines for Soil and Rock Logging" (AEG et al. 1994) provide a comprehensive list of descriptors to be used and the definitions thereof, to facilitate good understanding and communication between the recorder of the soil or rock conditions and the user of the information.

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