CHAPTER 2

TERRAIN EVALUATION CRITERIA

2.1 INTRODUCTION

In order to understand the different geotechnical classification systems previously and currently used in South Africa that will be discussed in the following chapters, the factors which should be taken into consideration during a regional geotechnical mapping process should be defined and explained. It is important to know how such features are recognized and classified. This will include geotechnical factors, construction materials and environmental considerations.

2.2 GEOTECHNICAL FACTORS

The different geotechnical factors are explained below in alphabetical order. This include a definition of each geotechnical factor, identification of the factor by means of field observation, laboratory testing and the associated implications of the factor on development.

2.2.1 Active, Expansive or Swelling soil

Expansive clays are probably the most widespread of problem soils in South Africa (Williams *et al.*, 1985). Damage to structures placed on potentially active soils may occur where the expansiveness has not been quantified and remedial measures not employed (Weaver, 1990). Most clayey soils change in volume as their moisture content changes seasonally where the amount of volume change depends on the type and amount of swelling clay in the soil. Shrinkage occurs mainly during the dry season and swelling during the wet season. Clay minerals can be broadly divided into swelling and non-swelling clays. Non-swelling clays are associated with regions of high temperature and high rainfall, where the bases are removed as soluble compounds and transported from the soil to leave an insoluble weathered residue of silicates in which kaolinite is the dominant, non-swelling, 1:1 lattice type clay mineral (Williams *et al.*, 1985). With decreasing rainfall or impeded drainage, chemical weathering becomes less intense and soluble bases released by weathering are not leached from the soil. This leads to the formation of the 2:1 lattice clay minerals in which successive sheets in the crystal structure contain varying amounts of water molecules (Williams *et al.*, 1985). It is the change in the amount of this water which causes swelling or shrinkage of the sheet structure and hence of the soil mass as a whole (Williams *et al.*, 1985). Soils with a large proportion of the smectite group clay minerals (e.g. montmorillonite) have the greatest shrinkage and swelling characteristics.

Expansive soils are usually recognized in profile by their colour and structure being often black, dark grey, red or mottled yellow-grey but seldom light grey, brown or white. They show slickensiding or shattering, which is distinctive evidence for heaving conditions (Williams *et al.*, 1985). The parent material, climate and landform is the most important factors in the formation of expansive soils. Expansive soils are associated mainly with areas where the underlying bedrock geology is basic in composition (e.g. andesite and dolerite) and with low-lying areas, such as flood-plains, pans and drainage channels. The amount of expected heave also generally increases downward from a hill crest to a gully. A factor that may reduce the influence of heave on potential development is the presence of a ferricrete layer overlying residual expansive soils (Carr, 1995).

The potential expansiveness of a soil depends upon its clay content, the type of clay mineral, its chemical composition and mechanical character (Van der Merwe, 1964). The plasticity index and linear shrinkage of soil samples can be used to indicate the soils potential expansiveness. A material is potentially expansive if it exhibits the following properties (Kantey and Brink, 1952):

- a liquid limit of more than 30%,

- a plasticity index of more than 12%,
- a linear shrinkage of more than 8% and
- a clay content greater than 12%.

The method of Van der Merwe (1964) can be used to determine the potential heave of soil samples. The expected potential heave ranges from low, medium, high to very high. Although this method is widely used in South Africa, it may over estimate the potential for expansion. This is ascribed to it's reliance on the plasticity index and clay percentage (fraction of soil passing the 2 micron sieve) of the soil, where the clay fraction can comprise a significant amount of non-swelling minerals such as quartz and calcite. Other laboratory tests that could be conducted on expansive clays include the double oedometer test and Brackley's Equation (Brackley, 1975), where the swell percentage is expressed as a function of the plasticity index, original moisture content, external load and the original void ratio. Brackley also developed a second empirical relationship where swell is expressed as a function of the plasticity index, moisture content, density and soil suction (Brackley, 1980).

Williams et al. (1995) determined that there is a linear relationship between percentage swell and the natural logarithm of applied load both for when swell takes place under constant load and under decreasing load, during studies of the volume change behaviour of various undisturbed soil samples in oedometers. The following generalized swell equation was derived from these studies:

$$\text{Swell \%} = \text{Free swell \%} \left(1 - \frac{\log_{10} P}{\log_{10} Ps} \right)$$

The free-swell is measured on a sample under a nominal 1 kPa applied pressure (P). Ps is the swelling pressure of the soil. The percentage swell can therefore be determined under any applied pressure once the free-swell and swelling pressure of the soil have been established.

2.2.2 Collapsible soils

Collapsible soils are soils, which can withstand relatively large imposed stresses with small settlements at a low in situ moisture content but will suddenly decrease in volume causing relatively large settlements when wetting occurs under a load, with no increase in the load. This volume change is associated with a change in the structure of the soil. The following four conditions need to be simultaneously satisfied before collapse will occur according to Schwartz (1985):

- The soils exhibit a collapsible fabric. A collapsible fabric may occur in any open structured silty, sandy soil with a high void ratio (low dry density).
- Partial saturation of the soil is required as collapse settlement will not occur in soils below the water table.
- There must be an increase in moisture content. The bridging colloidal material undergoes a loss of strength and the soil grains are forced into a denser state of packing with a reduction in void ratio.
- The soils need to be subjected to an imposed pressure (e.g. single storey house) greater than their natural overburden pressure.

According to Brink *et al.* (1982) the collapse phenomenon could be associated with colluvial sediments situated on straight slopes, plains and residual soils on well-drained hill slopes, that are derived from weathered granite, sandstone or quartzite.

Collapsible soils can be recognized in profile by a dry to slightly moist moisture content indicative of partial saturation, a loose to very loose consistency, open structure, silty sand to sandy silt soil matrix and the presence of colloidal coatings and clay bridges. Another way to identify soils with a collapsible grain structure in the field, is the reduction in volume that will be observed when a test pit is backfilled. If the soil has a collapsible grain structure it will fail to fill the pit completely, whilst with other soils one would find a bulking factor.

A collapsible fabric could be diagnosed in several ways by means of laboratory procedures. Analysis of the particle size distribution could be done in two ways, 1) If the particle size distribution reveals silty or sandy soils with a low clay content (< 20 %) not enough clay is present as cement between grains to support the soil structure and a potential for collapse exist (Brink *et al.*,1982), 2) An indication of the collapse potential of the soils is obtained by comparing the grading curves of the material with a set of grading limits defined by the grading curves of samples proven to be collapsible as determined by Knight (1961) and Errera (1977). Any soil with a dry density of <1600 kg/m^3 should be regarded as potentially collapsible, the high void ratio of collapsible soils impart low dry densities in the range of 900 - 1600 kg/m^3 (Brink *et al.*,1982). The collapse potential test is an index test, which assists in the identification of potentially collapsible soils during regional geotechnical mapping. This method however is widely used to quantify the severity class of collapse. The severity classes range from no problem, moderate trouble, trouble, severe trouble, to very severe trouble. The most reliable method to determine the amount of collapse is by means of the double oedometer test (Brink *et al.*,1982).

2.2.3 Compressible soils

Poorly consolidated or highly compressible soils are liable to consolidate under applied loads, leading to settlement (Brink *et al.*, 1982). The compressibility of a soil depends on the structure of the soil (arrangement of the soil particle packing) and the hydrostatic pressure. Compressible soils usually have a high moisture content and unorientated loose packing, so if pressure is applied, the particles re-align themselves and disperses most of the water - hence compression occurs (Price, 1981).

This type of settlement is commonly associated with recent alluvial deposits (e.g. soft clays in flood plains) which have not been significantly desiccated or compressed by temporary loads (e.g. deep sedimentary mantles subsequently removed by erosion) and have consolidated only under their own overburden pressure (Brink *et al.*, 1982). Poorly consolidated soils can also develop on plains or very gentle straight slopes.

The amount of settlement is dependent on the applied load (e.g. single-storey house), the moisture content and the structure of the soil. The amount of settlement of a soil can be determined by means of testing an undisturbed sample in a consolidometer.

Poorly consolidated soil gives shear strength problems (low bearing capacity), compressibility and time related settlement problems, especially in embankments. The most practical foundation technique available for this problem is conventional piling where the load of the structure is transmitted by piles to deeper and stronger horizons or the use of *in situ* densification methods in more sandy deposits.

2.2.4 Dispersive soils

Dispersive soils are prone to disaggregation or deflocculation in contact with water. This could cause failure of slopes, earth dams and embankments where piping erosion of dispersive clay soils starts along zones of high soil permeability (e.g construction planes, desiccation cracks, etc.).

The dispersivity of a soil is a measure of its susceptibility to erosion. The tendency for dispersive erosion in any given soil depends upon such variables as the mineralogy and chemistry of the clay and the dissolved salts in the soil water and the eroding water (Elges, 1985). High exchangeable sodium percentage (ESP) values and piping potential exist in soils where the clay fraction is largely composed of smectite and other 2:1 clays (e.g. montmorillonite). Dispersion occurs when the repulsive forces (electrical surface forces) between individual clay particles exceed the attractive (van der Waal's) forces so that when the clay mass is in contact with water individual clay particles are progressively detached from the surface and go into suspension (Elges, 1985). If the water is flowing the dispersed clay particles are carried away. The main property of the clay governing the susceptibility to dispersion piping is the percentage absorbed sodium cations on the surface of the clay particles relative to the quantities of other poly-valent cations (calcium, magnesium or aluminium) (Elges, 1985). The second factor governing the susceptibility of the clay mass to dispersion piping is the total content of dissolved salts in the carrying water. The lower the content of dissolved salts in the water, the greater the susceptibility of sodium saturated clay to dispersion (Elges, 1985).

Dispersive soils are typical of certain areas and certain geological settings and will develop under the following circumstances (Elges, 1985):

- Low-lying areas where the rainfall is such that seepage water has high SAR (sodium absorption ratio) values and in regions with a N-value >2. Soils developed on granite are especially prone to the development of high ESP values in low-lying areas.
- Areas where the original sediments contain large amounts of 2:1 clays (montmorillonite, vermiculite) with high ESP values. Particularly with mudstones and siltstones of the Beaufort Group and the Molteno Formation in regions with a N-value >2. In these regions soils in low-lying areas will virtually without exception be dispersive.
- The development of dispersive soils in the more arid parts (N-value > 10) is inhibited by the presence of free salts, despite high SAR values. Highly dispersive soils can develop, should the free salts with high SAR values be leached out.

According to Elges (1985) dispersive soils can be recognised in the field by the following features:

- Gully erosion (dongas) and field tunnelling (piping and jugging).
- Washed-out clay fans with a very pale colour.
- Areas of poor crop production indicative of high saline soils which are dispersive.
- Calcrete formations above a clay horizon, observed from exposed cuttings.
- A clay soil which softens rapidly with a greasy feel, on contact with water.
- Dispersive soils with a high content of smectite clays and a PI>30, have a fairly high swell potential and are very impervious. If the soil layer is wetted only to a depth of 4 centimetres after heavy rains, one may suspect a dispersive soil.

Laboratory tests include the Soil Conservation Services double hydrometer test, the Emerson crumb test, the pin-hole test, test of dissolved salts in the pore water and the chemical (ESP based) test. The most reliable test being used is the chemical test (ESP based). The Emerson crumb test (index test) is normally used during regional geotechnical mapping and consists of a 15 mm cube specimen placed in 250 ml distilled water. As the soil crumb begins to hydrate the tendency for colloidal sized particles to deflocculate and to go into suspension is observed. Four grades are discernable: 1-no reaction, 2-slight reaction, 3-moderate reaction, and 4-strong reaction. The crumb test generally gives a good indication of the potential erodibility of clay soils.

2.2.5 Excavatability of ground

The ease of excavation is a critical financial factor for development when installing underground services and placement of foundations. The excavatability of ground is described in terms of the ease with which ground can be excavated or dug out to a depth of 1,5m. The ease of excavation depends on the consistency (e.g. very stiff clays are difficult to excavate), type of material, presence of boulders and bedrock weathering depth. The severity classes of excavatability range from slight (can be hand dugged), moderate (back-actor is required), to severe (blasting and/or power tools required). The excavatability is determined during fieldwork, whilst digging test pits or augering of boreholes.

Weaver (1975) utilized the geomechanical classification system of Bieniawski (1973) and developed a rippability rating chart, during which the geological factors that are significant in the evaluation of characteristics of earth and rock materials are described and a guide to the assessment of rippability by tractor mounted rippers are given. The geological factors taken into consideration include: Rock class, seismic velocity (m/s), rock hardness and weathering, joint spacing (mm), joint continuity, joint gouge, strike and dip orientations. Each of this geological factors have specific ratings, a total rating are determined by adding the points of the different factors together and from there a rippability assessment can be made.

The South African Bureau of Standards (SABS) has a specific subclause on the classification of materials for excavation, during contract cost estimates. According to SABS 0120: Part 5, Section D-1982, the following classes of excavation must be used during cost estimates:

- Soft excavation: Material capable of sustaining plant life and removed to a depth of 150 mm or as otherwise ordered, for use as topsoil, is classified as soft excavation.
- Hard rock excavation: Unweathered or undecomposed rock in thick ledges, bedded deposits, or conglomerate deposits so firmly cemented together as to present all the characteristics of solid rock that cannot be efficiently loosened, dislodged, or excavated without the use of explosives is generally classified as hard rock excavation.
- Boulder excavation Class A: The inclusion in the definition of boulder excavation Class A of the phrase "40% by volume of boulders" is an important criterion which has the effect of changing the classification of a particular material from "boulder Class A" to "hard rock" as the plan dimensions of the excavation change from those of a large open area such as a road cutting or a foundation for a major structure to those of a confined area or trench-like shape such as the individual footings for a structure or a pipe trench.

Both the criteria of Weaver and the SABS is applicable to site specific investigations and not for use during regional geotechnical mapping.

2.2.6 Inundation (flooding)

Inundation affects the use of low, flat lying areas, confined to drainage channels and flood plains. Floods are natural events that have to be taken into account where development encroaches on or close to stream channels. Therefore most residential development, such as houses, cannot be erected in areas below the 1:100 year flood line (DFA, 1995) and these areas should be indicated on the geotechnical map. Note should be taken however, that certain developments may have significant affects on the flood behaviour of a river. Factors such as changed hydrology, sediment loads and river diversions can have significant impacts to the extent that areas before development with a low risk of flooding can become high risk areas after development. Development planning also should be aware of the impact of altered flow and flood patterns on the abiotic and biotic life in sensitive environments such as wetlands.

2.2.7 Pseudokarst

Granitic soils are susceptible to pseudokarst formation because their particle distribution allows for the washing out of fine material given a sufficient hydraulic gradient (Brink, 1979). This phenomenon is produced by the mechanical and chemical action of water through which finer materials are washed out from between coarser particles by selective mechanical suffosion or piping (Brink, 1979). The dispersiveness of the soil contributes to this particular problem. This problem is associated predominantly with the flow of water along side roads and drainage channels. Pseudokarst conditions can only be determined by the excavation of test pits during site specific investigations.

2.2.8 Shallow water table

A shallow water table is where the top of the permanently saturated zone occurs close to the ground surface. This definition also includes a perched water table where geological conditions result in a local zone of saturation that is higher than the regional water table.

A shallow water table could occur in alluvial plains and topographical flat areas. During the wet summer months, these areas may be inundated with water, thus reducing the bearing capacity of the soils and / or providing for seasonal problems relating to cyclic shrink-swell effects occurring within swelling clays. It is advised that precautionary measures be taken to allow for the drainage of water from excavations during construction to prevent instability in cut clay slopes. A shallow water table is also vulnerable to contamination by incorrectly sited facilities such as waste sites, pit latrines and cemeteries. It can also be regarded as a cost factor, due to the negative impact on structures resulting from rising damp and possible damage to sub-surface services due to a bouancy effect.

A fluctuating water table could be recognized in test pits as pedogenic concretions (e.g. ferricrete) tends to develop at the base of a current or previous perched water table.

2.2.9 Sinkhole formation

Areas underlain by dolomite exhibit a potential for sinkhole or doline formation, which is a serious geological hazard that can lead to structural damage, draining of water features, the contamination of groundwater and loss of life. Dolomitic land is defined as areas, which are directly underlain by dolomite or where dolomite is found within 100m of the surface (Buttrick *et al.*, 2001).

Triggering mechanisms in the formation of sinkholes are the downward percolation of water from leaking services and the lowering of the groundwater table (e.g. mining activities and municipal use). This enhances the weathering and dissolution process of the dolomite to form unstable cavities which are left unsupported when the groundwater is lowered. Sinkholes are formed by dissolution weathering of the carbonate minerals within the rock mass by groundwater containing carbon dioxide (Brink, 1979). These voids enlarge with time as the weathering process continues. Fractures in the rock are enlarged and eventually results in sinkholes.

A sinkhole can be defined as a surface subsidence which occurs suddenly, as a cylindrical and very steep-sided hole in the ground, usually but not always, circular in plan (Brink, 1979). A compaction subsidence or doline can be defined as a surface depression which appears slowly over a period of years (Brink, 1979). It may be circular, oval or linear in plan.

The scale on which regional geotechnical mapping is conducted doesn't permit the determination of sinkhole formation severity classes for any particular area. A detailed site investigation including gravity surveys, drilling and test pits with a risk assessment, is required for areas underlain by dolomite before development can proceed. Precautionary measures and specified founding methods should be employed in areas that are underlain by dolomite.

2.2.10 Slope stability

Residential development is favoured on slopes with a gradient of less than 12°, with the exception of the Kwazulu-Natal and Mpumalanga provinces where a gradient of less than 18° is allowable.

Slope instability could be defined as areas comprising unstable geological materials that could move down slope either gradually (creep) or suddenly as a slump or a slide. The risk of slope instability is determined by natural or induced factors. Natural factors include, the nature of the slope (solid rock or soil-density, angle of internal friction, cohesion), gradient of the slope, role of water (height and fluctuation), type and nature of vegetation cover, orientation of linear structures (e.g. joints, fault zones, fracture zones, dykes) and seismicity. Induced factors are those which are as a result of human activities (e.g undermining of a slope during excavation of roads or structural developments). Induced slope instability can also be caused by mining activities such as mine dumps, opencast mines and quarries, where the height of the slope and the angle of the slope exceeds the angle of internal friction of the natural material.

During geotechnical mapping areas are also mapped according to their risk of becoming unstable due to human activity (e.g. road cuts).

2.3 CONSTRUCTION MATERIALS

When locating potential quarries for construction and building materials the following should be considered (Zawada, 2000):

- Their close proximity to urban areas, to keep transport costs to a minimum.
- Close liaison with town and regional planners to relate the operational life of the quarry with the long term land use and development plans of adjoining areas.
- The environmental implications of establishing a quarry close to an area of rapid development such as the aesthetic impact, dust, smoke, water and noise pollution, excessive traffic and the legal restrictions of an operating quarry.
- Urban encroachment has led to the sterilization of potential construction material resources in the past. It is therefore important for planners to be aware of the occurrence of potential construction materials during land-use planning.

All existing quarries (non-operational and operational), as well as potential resources should be indicated on the map. If the potential resources are not indicated, it should be defined and described in the report/explanation accompanying the map. The environmental aspects of disused quarries should also be discussed.

Potential natural resources consisting of brick-making clays, aggregates (fine and coarse), road material, dimension stone and mineral deposits, should be defined in terms of suitability, quality and available reserves. The requirements as set out for brick-making clays, coarse aggregates and building sand, should be used to determine the suitability and quality of materials (Morrison, 1980). The evaluation of sound construction materials to be used in roads, should be done according to the reference work by Weinert (1980).

2.4 ENVIRONMENTAL CONSIDERATIONS

The assessment of facilities such as cemetery sites, waste disposal sites and ground based sanitation systems (pit latrines/septic tanks) should take specific soil conditions into account, that could have a negative impact on the environment (e.g. contamination of water, groundwater, soil and air by organic and inorganic pollutants). Comment is given on the general soil conditions of these environmentally sensitive facilities. The requirements for each facility are discussed in the following paragraphs.

2.4.1 Cemetery sites

A number of requirements have to be met for a particular area to be suitable for use as a potential cemetery site. These include the following (Fisher, 1994):

- Surface gradient of between 2° and 6° (up to 9° in extreme cases) to ensure adequate site drainage, minimum erosion and to promote human and mechanical mobility on site.
- A deep soil profile of at least 1,80 metres for ease of excavation (preferably hand tool excavation).
- A soil consistent enough so that the stability of grave walls is maintained for a few days. Soil consistency of at least medium dense for non-cohesive soils and/or firm for cohesive soils.
- A low permeability (10^{-5} cm/s to 10^{-6} cm/s) of underlying soils to prevent ground water contamination.
- A particular location such that the site is situated at least 100 metres from the 50 year flood-line of drainage channels.
- Ground water level, perched or permanent, must be deeper than 4 metres.
- A buffer zone of at least 2,5 metres below the base of the graves and top of the ground water level.
- No drainage channels through the proposed area.
- Dolomite should not occur as the underlying geology.
- Borehole drinking water at a minimum safe distance of 500 metres from the terrain.
- Large enough area for future extensions (3000 graves per hectare).

2.4.2 Waste disposal sites

Requirements for waste disposal sites as outlined by the Department of Water Affairs and Forestry (DWAF, 1998). There are a number of requirements that have to be met, for a particular area to be suitable for use as a potential waste disposal site. These include the following:

- A deep soil profile of at least 1,5 metres for excavation and provision of adequate cover material.
- Soil cover material must be of good quality (USCS soil classes: CL, SC or GC) and sufficient volume for 10 to 15 centimetres compacted cover per day.
- The underlying material should be of moderate permeability (10^{-3} to 10^{-5} cm/s) to ensure sufficient attenuation of leachate.
- Aesthetical placing of the site, preferably out of sight and downwind of residential and urban areas.
- The site must be secure from flooding (above the 1:100 year flood-line) and away from drainage channels and surface water bodies.
- A vertical buffer zone of 2,0 to 3,0 metres between the bottom of the waste and the highest groundwater level and 500 metres from the nearest borehole.
- A large enough site for the expected volume of waste for at least the next 10 to 15 years.
- Limited or controlled entry to prevent risk to humans.

2.4.3 Ground based sanitation systems (pit latrines / septic tanks)

Pit latrines (wet system) are normally adopted were the volume of liquid waste is small and evaporation is high, septic tanks (semi-wet system) are installed for large volumes of liquid waste.

Both require soils of suitable permeability, since both involve a subsoil percolation disposal system. Magni and du Cann (1978), state that approximate permeability limits of soil in which pit latrines are to be dug should be less than 4×10^{-3} cm/s to prevent pollution and more than 5×10^{-4} cm/s to be sufficiently permeable to allow for attenuation of the effluent. A higher permeability value may be permissible where the water table is very deep or where there are no water supply boreholes in the immediate vicinity. These ground based systems should not be sited in highly permeable sandy or impermeable clayey soils.

Apart from permeability, there are a number of other requirements that also have to be met to prevent excessive pollution occurring in areas that utilise ground based sanitation systems. Sanitation systems should not be sited in areas were the following conditions occur (after De Villiers, 1987):

- Within shallow bedrock or difficult excavation conditions. At least 2 metres of suitably permeable and excavatable soil is required from the surface to the base.
- Located uphill or within 30 metres of a groundwater source.
- Sited within 6 metres of a house.
- Preferably, dolomite should not occur as the underlying geology.
- Within a perched or shallow water table.
- In the immediate vicinity of drainage features and drinking water extraction points.
- Sited in soils of loose or soft consistency, that can cause unstable pit walls.