Central University of Technology, Free State

DEVELOPMENT OF AN INFORMATION SYSTEM FOR GEOTECHNICAL ENGINEERS TOWARDS IMPROVED DECISION MAKING

by

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A dissertation submitted in fulfilment of the requirements for the degree
Master of Engineering in Civil Engineering
in the
Department of Civil Engineering
of the
Faculty of Engineering, Built Environment and Information Technology
of the
Central University of Technology, Free State, South Africa

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August 2022

DECLARATION

I, the undersigned, declare that the dissertation hereby submitted by me for the degree *Master of Engineering in Civil Engineering* at the Central University of Technology, Free State, is my own independent work and has not been submitted by me to another university and/or faculty in order to obtain a degree. I further cede copyright of this dissertation in favour of the Central University of Technology, Free State.

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ABSTRACT

A desktop study is an initial, relatively inexpensive study performed by a geotechnical engineer before a site investigation to provide an understanding of the site, identifying potential risks and enabling the engineer to make decisions on the approach of the site investigation. Desktop studies often also include relevant geotechnical data from previous construction works on and around the site in addition to other information. Developing an information system for South Africa that is easily accessible for engineers to view data geographically and transform the data into reliable, meaningful information will assist towards informed decision-making by these engineers during the desktop study phase and later phases of a project.

The Information System for Geotechnical Engineers (ISGE) was developed with all the specifications, identified during the literature review, to assist South African geotechnical engineers (and other experts). The database and interface use the SANS3001 codes which are currently not available in other software, as determined through a thorough study of available software.

The geotechnical engineering database was developed using Microsoft Access to store the geotechnical engineering test and site data. This avoids the need for physical space for paper filing. The database allows users to find specific information quickly and with ease and enables them to sort through the data seamlessly. This allows users to process existing data for better decision-making while also being very secure and preventing users from accidentally deleting records or accessing private information.

An information interface was developed that transforms data from the information in the database to create geotechnical outputs on Microsoft Excel. This allows the user to search for any existing samples, layers or test pits and to view the relevant inputs and outputs for those tests. To improve decision making, a summary page interface that summarises the geotechnical information was developed in the information interface as well. This access to information allows engineers to observe a large quantity of different information in detail to compare and make a comprehensive assessment of the site and all the geotechnical properties of that area.

The ISGE has the capability to export the information in a file format supported by GIS software. Using GIS makes interpreting the potential problems of areas much easier for engineers who can observe the surrounding data and make valid assumptions about their study areas.

ACKNOWLEDGEMENTS

A number of special acknowledgements deserve specific mention:

(a) Acknowledgement above all to my Heavenly Father for setting my feet on a rock and making my steps secure (Ps. 40).
(b) The Rectorate and relevant functionaries from the Central University of Technology, Free State, for the opportunity to complete this research;
(c) Prof E Theron, my supervisor, for guidance and support given in my career, research and personal growth. I trust that we will still walk a long path together;
(d) Mr CH Wessels, my co-supervisor, for guidance given throughout the project and eagerness to assist me;
(e) My parents, my brother, Tania, Tiaan, my uncles and aunts, cousins, Breggie, and all the others who have been in my life, for their patience and understanding throughout this research
(f) My colleagues from the Central University of Technology; and
(g) The Soil Mechanics Research Group (Johno, Yannis, Dewald, Vivian, Malelo, Daandre, Socrates, Obert, Dr Stott and WIL students) for all their assistance, hard work and support of my research.

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LIST OF ABBREVIATIONS

ESRI	Environmental Systems Research Institute
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BS	British Standards
CBR	California bearing ratio
COLTO	Committee of Transport Officials
CSV	Comma-separated values
DOT	Department of Transport
GE	Geotechnical engineer
GIS	Geographical information systems
IS	Information system
ISGE	Information system for geotechnical engineers
KML	Key Markup Language
LL	Liquid limit
MDD	Maximum dry density
OMC	Optimum moisture content
PI	Plasticity index
PL	Plastic limit
SABS	South African Bureau of Standards
SAICE	South African Institution of Civil Engineering
SANRAL	South African National Roads Agency
SANS	South African National Standards
SAPEM	South African Pavement Engineering Manual
SL	Shrinkage limit
USCS	Unified Soil Classification System
VBA	Visual Basics for Applications

CHAPTER 1: INTRODUCTION

1.1 Rationale and Motivation for the Research

Site Investigations, according to the Site Investigation Code of Practice produced by the South African Institution of Civil Engineering (SAICE) divides a site investigation into several phases as part of good practice. These phases are listed below:

1. Project start-up
2. Pre-feasibility
3. Feasibility
4. Design
5. Construction
6. Post Construction

During the first three phases the entire site is assessed in terms of its feasibility for the construction, site risks are identified, geotechnical constraints are identified, existing data is considered, and a conceptual geotechnical model is formulated from this information. A proper desktop study needs to be executed for these three phases (SAICE, 2010).

A desktop study is an initial study performed by a geotechnical engineer at the initialization of a site investigation. This is a preliminary study carried out before more detailed geotechnical investigations are executed. It is a relatively inexpensive method for providing an initial understanding of the site, identifying potential risks and enabling the engineer to make decisions on the approach of the site investigation. The desktop study usually includes mapping (such as topographical maps) and any relevant geotechnical data from previous construction works on and around the site. However, previous site information could be challenging to find, especially in South Africa where geotechnical engineers do not have access to data. New geographical information systems (GIS) are rapidly replacing traditional aerial photographs and maps.

Developing an Information System for Geotechnical Engineers (ISGE) that allows the user to view and transform topographical, geological, and other data with full geographical control, will produce reliable and meaningful information to make informed decisions by the engineering team from the early stages of exploration and conceptual modeling. This information will serve as the base information layers for a building project throughout its lifetime.

Decision-making is the study of defined alternatives based on the decision-maker's principles and preferences. During the planning phase of a site investigation, decision-making should define as many alternatives as possible and the best alternatives that best matches the stakeholder's priorities, objectives, and requirements (Montasaera & Montaserb, 2017). A core civil engineering undertaking is making decisions that meet project objectives in the face of uncertainty and within a given time frame. It would be ideal if these decisions could take all matters into account; however, time, money and other constraints could still hinder the decision-making process (Rodriguez-Nikl & Brown, 2012). Modern computer support systems do allow for much more data to be processed and more streamlined workflow for planning and design stages.

The first steps in documenting soil information on a broader scale in South Africa were taken in the late 1930s, concluding CR van der Merwe's publication *Soils of South Africa*. This publication tried to gather all available knowledge, both first-hand and assumed, to produce a very small-scale national soil pattern map (approximately 1:2 500 000). With this first attempt as a starting point, the expansion and increasing mechanisation and modernisation of agriculture in South Africa in the 1950s began to recognise the need to increase soil knowledge across the more productive areas of the country (Paterson et al., 2014).

Inadequate geotechnical investigations often lead to structural failure when there is insufficient information during the desktop study. Storing data could assist engineers in performing new desktop studies near areas previously investigated. Currently, data is often lost or not easily accessible owing to poor storage systems used by engineers. Therefore, an initial design of an information system geotechnical engineering (ISGE) was proposed for this study.

The focus of the system's development was that it was to be easily accessible and assist engineers in making critical decisions for a geotechnical site investigation during the desktop study phase. The ISGE needed to be defined before its development was initiated. Therefore, a list of requirements was specified for the system. These requirements included all the geotechnical engineering requirements and properties that would further define the system. The need for an ISGE in South Africa was examined, and a comparison was made with software available from other countries that have already developed similar systems. Assessing information systems and databases was completed to determine the demand for an ISGE in South Africa.

An information system for geotechnical engineers was created based on the requirements to store data and transform data into reliable, meaningful information. This will assist towards informed decision-making by the engineer during the desktop study before a project is initialized. It stores data (through the Microsoft Access database) linked to the interface (Microsoft Excel) that transforms the data into information through queries. The tables in the database are linked to their respective worksheets on the interface. These are linked to the final summary page. The summary page shows all the essential information from each laboratory test and assesses the results to assist in decision-making. Furthermore, all the accumulated data can be exported in GIS utilizable file formats (such as .kml and csv. files), enabling engineers to view the information geographically through geographical information systems (GISs), where data can be compared to nearby test pits from previous projects.

1.2 Hypothesis, Aims and Objectives

1.2.1 Hypothesis

An ISGE will assist South African engineers to compare and analyse geotechnical engineering information during the decision-making process of desktop studies.

1.2.2 Research aim

To develop an ISGE to be used by South African geotechnical engineers to assist them in making informed decisions during the desktop study.

1.2.2.1 Objective 1

To determine necessary tests and parameters for making informed decisions in geotechnical investigations. All these ‘entities’ will be measured on SANS3001 standards and regulations in South Africa.

1.2.2.2 Objective 2

To design and create a geotechnical engineering database to store geotechnical engineering test and site data.

1.2.2.3 Objective 3

To develop an information interface that transforms data from the information in the database to create geotechnical outputs expected by geotechnical engineers and display them.

1.2.2.4 Objective 4

To create a summary page interface that summarises the geotechnical information to improve decision-making during a desktop study.

1.2.2.5 Objective 5

To develop the capability for the system to export the information in a file format supported by GIS software for comparison of information near areas studied by the engineer during a desktop study.

1.2.3 Thesis Outline

The thesis is divided into six chapters. The first chapter provides a background, placing the study in the context of geotechnical engineering decision-making and the need for an ISGE in South Africa.

The second chapter studies all the laboratory tests and geotechnical investigations that are required for geotechnical investigations. The Standards and Regulations are also studied to ensure that the methods and values used are applicable in a South African context.

The third chapter compares some of the available software programs that assess geotechnical engineering data and store this data for future use and indicates which systems would be sufficient for decision-making. These programs are compared to the required criteria and SANS3001 standards.

In the fourth chapter, the procedure for developing the ISGE is discussed. First, the need for an ISGE is discussed. Then, the whole process of designing the proposed database using Microsoft Access, creating an information interface in Microsoft Excel and linking the entire system is explained.

Chapter 5 elaborates on the outputs of the ISGE, including the summary page and exportation of GIS-supported files. Finally, an explanation is given why the specific data was used, and decisions were made for the ISGE.

Chapter 6 concludes the research study by referring to some of the problems experienced during the study. Future expansions on the study are also discussed, and suggestions are made for further research projects.

Chapter 7 gives a list of references that were used in this study.

CHAPTER 2: LITERATURE REVIEW

The information system for geotechnical engineers (ISGE) could only be used if the information stored and transformed in the ISGE relates to geotechnical engineering tests and procedures used by South African engineers. Therefore, this chapter focuses on these fundamentals of geotechnical tests that would be developed in the ISGE to understand the requirements for the storage and transformation of data in the ISGE.

Geotechnical engineering is the sub-discipline of civil engineering which involves natural materials found near the earth's surface. It includes applying soil mechanics and rock mechanics principles to foundation design, retaining structures, and earth structures. Soil mechanics is the branch of science concerned with the study of soil's physical properties and the behaviour of soil masses subjected to various types of forces. Geotechnical engineering is the application of soil mechanics principles to practical problems (Das, 2017).

2.1 Importance of Geotechnical Engineering

Soil is used in various civil engineering projects as a construction material for roads and it supports structural foundations. Therefore, civil engineers need to research the properties of soil, such as its origin, distribution of grain size, state, compactability, shear strength and load-bearing capacity (Das, 2017).

These properties and geotechnical surface conditions play a vital role in most construction processes. The geotechnical situation at and around the construction site can significantly impact the planning and implementation of the construction process and design as well as the security of the construction itself. Various examples worldwide show that the geotechnical conditions should not be neglected during any construction process (Tegtmeier, Zlatanova, Oosterom, & Hack, 2009). These properties of soils need to be understood and incorporated into the ISGE for it to be a useful tool for engineers to use in decision-making during the desktop study phase of projects and possibly during the design phase as well.

2.2 Site Investigations

According to the Home Building Manual, a geotechnical site investigation means the process of evaluating the geotechnical character of a site in the context of available or proposed works or land usage (Asmaa, 2014). Owing to the wide variety of soil types and conditions that can be encountered, it is essential to conduct a site investigation before design work begins. It is essential for the analytical design approach to evaluate and identify the soil's moisture content, colour, consistency, type of soil, and soil structure (SABS, 1995).

Typically, a site investigation will cover the following elements:

- The desktop study should include a study of published geological and topographical maps, aerial photographs, ortho-photographs, geo-hydrological maps or any other relevant data from previous works on and around the site. The ISGE would allow engineers to store and view relevant data as required from a desk study.
- Test pits are excavated and profiled in situ to develop site stratigraphy, identify seepage behaviour, assess the stability of the slope for excavations, and sample for laboratory testing. Test pits are relatively cost-effective investigative instruments that provide valuable information. Laboratory test results and the profiles will be transformed into information and shown in the ISGE into GISs.
- Laboratory tests offer the most practical and accurate means of classifying and characterising geo-materials if samples obtained and tested are representative, and in some cases, undisturbed (SAICE, 2010).

2.3 Report

The person conducting the site investigation must ensure that the engineer prepares and produces a report. Such a report should contain an acceptable description of the soil profiles, information on groundwater conditions, the results of soil tests, information on the presence of expansive or collapsing soils and the possibility of sinkhole formation, and recommendations on the type and design of the foundations and any special measures required during construction, along with any additional measures. The content found in typical site investigations reports is essential for geotechnical engineers and should be added to the ISGE to complete the information provided for engineers to have a better understanding of the site and area.

2.3.1 Description of field and laboratory investigations

This part of the report should include a complete discussion of the type of investigative methods, including the following:

- The execution dates
- Number of tests and location
- Procedures used for testing
- Exploration depth
- Relevant observations or notes

The data is generally presented in its raw format, without interpretation, classification or characterisation, but can be summarised for ease of reference in table or graph format. Appendixes typically present profile records, test results, and other supplementary details.

2.3.1.1 Materials

As determined by field and laboratory investigations, the cumulative factual data on the site materials are used to classify and characterise materials in terms of their engineering properties and behaviours, including structure, strength, compressibility, and consolidation. Fatal geotechnical flaws that would limit the proposed development are identified and stated (SAICE, 2010).

2.3.1.2 Soil profile

The profile found in any test pit or inspection pit may consist of several layers that can be distinguished by the following:

- Changes in moisture state
- Colour
- Hardness
- Consistency
- Presence or absence of joints or cracks
- Difference in grain size

Any significant change in one or more of these properties determines a change in the layer or stratum of soil. The procedures recommended for field observation of the condition of moisture, colour, consistency, structure, soil type, and origin of soil profile layer (abbreviated as MCCSSO) are given below (SABS, 1995).

2.3.1.3 Moisture condition

The moisture condition of the layer of soil should be described as a necessary precursor to the consistency assessment, which depends on the moisture content at the time of inspection. Moisture is recorded as one of the following: dry, slightly moist, moist, very moist, or wet. The assessment of moisture condition provides a useful indication of the water requirements for compaction (SABS, 1995).

2.3.1.4 Colour

The colour is important for describing the soil and correlating the same layer in different holes in the same general area. It is also important for identifying layers for subsequent instruction to excavators. Many soils, particularly alluvial clays, are mottled by the presence of small exposures of a different colour. These colour differences are a result of chemical changes associated with seasonal changes in moisture content. A proper description of the colour is complex, and few observers agree when their observations are made subjectively. The most satisfactory basis is provided by comparing the colours with those standards laid down in colour charts. The SAICE has prepared a simplified soil colour disc, the Burland colour disc. A similar abbreviated chart has also been compiled by the Soil Research Institute at the Department of Agricultural Technical Services in Pretoria (SABS, 1995).

2.3.1.5 Consistency

Consistency is the measure of the hardness or toughness of the soil. It is an observation based on the effort required to dig into the soil or mould it with the fingers. As these operations involve shearing, the assessment of consistency is a rough measure of the shear strength of the soil.

The need to separate soils into cohesive and non-cohesive classes to describe consistency arises from the differences in permeability or drainage characteristics which profoundly affect shear strength. The following two tables (Tables 1 and 2) assist in classifying the consistency of soils (SABS, 1995).

Table 1 - Consistency of granular soils (SABS, 1995)

TABLE B-1 – CONSISTENCY OF GRANULAR SOILS		
1	2	3
Gravels and clean sands, generally free-draining		Typical ranges of dry density, kg/m^3
Very loose	Crumbles very easily when scraped with geological pick	Less than 1450
Loose	Small resistance to penetration by sharp end of geological pick	1450 – 1600
Medium dense	Considerable resistance to penetration by sharp end of geological pick	1600 – 1750
Dense	Very high resistance to penetration by sharp end of geological pick; requires many blows for excavation	1750 – 1925
Very dense	High resistance to repeated blows of geological pick; requires power tools for excavation	More than 1925

Table 2 - Consistency of cohesive soils (SABS, 1995)

TABLE B-2 – CONSISTENCY OF CHESIVE SOILS				
1	2	3	4	5
Designation	Silts and clays, and combinations of silts and clays with sand, generally slow-draining		Typical ranges of unconfined compressive strength*, kPa	
S1	Very soft	Pick head can easily be pushed in as far as the shaft of the handle; easily moulded by fingers	Less than 35	Less than 25
S2	Soft	Easily penetrated by thumb; sharp end of pick can be pushed in 30-40 mm; moulded by fingers with some pressure	35-75	25-50
S3	Firm	Indented by thumb with effort; sharp end of pick can be pushed in up to 10 mm; very difficult to mould with fingers; can just be penetrated with an ordinary hand spade	75-150	50-100
S4	Stiff	Indented by thumbnail; slight indentation produced by pushing pick point into soil; cannot be moulded by fingers; requires hand pick for excavation	150-300	100-200
S5	Very stiff	Indented by thumbnail with difficulty; slight indentation produced by blow of pick point; requires power tools for excavation	More than 300	200-400

The engineer must note whether the cohesive soil is dry, fissured, or jointed. If joints exist, cracks may develop in tension zones and aggravate the effects of water (SABS, 1995).

2.3.1.6 Structure

The soil structure indicates the presence (or absence) of joints in the soil and the nature of these joints. Non-cohesive soils exhibit a granular structure, and as this is an invariable feature, it is usually not recorded. On the other hand, cohesive soils exhibit several types of structural characteristics (SABS, 1995).

Table 3 - Structural characteristics of soils (SABS, 1995)

Intact	Indicates an absence of fissures or joints. If soft, the soil may be plastic like butter, but if firm, it may exhibit tension breaks when cut with a pick
Fissured	Indicates the presence of closed joints. The joint surfaces are frequently stained with iron and manganese oxides. When cut with a pick, the soil tends to break along the joints.
Slickensided	Indicates the presence of fissures that are highly polished or glossy and frequently striated. Slickensides may be a sign of recent shearing movements in the soil, but similar shiny surfaces can also be developed on joint planes along which there has been no displacement.
Shattered	Indicates the presence of fissures in which joints have opened up and permitted the entry of air. The soil fragments are usually stiff or very stiff, and cubical or granular fragments are broken out when the soil is cut with a pick. Generally, the fragments break down with difficulty when wetted and worked on the hand.
Micro-shattering	Shattering on a small scale, the shattered fragments being of the size of sand grains. When micro-shattering is well developed, and the soil is cut with a pick, it appears granular, but these grains break down into clay or silt or some combination of clay and silt when rubbed with water on the palm.

2.3.1.7 Soil type

The soil type in every stratum is described based on grain size as described by Table 4.

Table 4 - Grain sizes in soils (SABS, 1995).

TABLE B-3 – GRAIN SIZES IN SOILS					
1	2	3	4	5	6
Grain Size, mm		Classification	Individual particles visible using	Mineralogical composition	Identification test
Greater than	Not greater than				
-	0.002	Clay	Electron microscope	Secondary minerals (clay minerals and iron-oxides)	Greasy feel; soils hands; shiny when wet
0.002	0.075	Silt	Microscope	Primary and secondary minerals	Gritty feel on teeth; when dry rubs off hands; dilatant
0.075	0.2	Fine sand	Hand lens	Primary minerals (mainly quartz)	Gritty feel on teeth
0.2	0.6	Medium sand			
0.6	2.5	Coarse sand			
2.5	12	Fine gravel	Naked eye	Rocks (sometimes vein quartz)	Observed with naked eye
12	50	Medium gravel			
50	200	Coarse gravel			
200	-	Boulders		Rocks	

1. Boulders are rock fragments of size greater than 200 mm. The rock types and ranges of sizes should be recorded.
2. Gravel consists of fragments of rock of size greater than 2,5 mm but not greater than 200 mm. The shape of gravel particles should also be described as this often aids in determining their origin. Terms to be used are the following:
    a. Well rounded (nearly spherical)
    b. Rounded (tending to oval shape)

   c. Sub-rounded (all corners rounded off)
   d. Sub-angular (corners slightly bevelled)
   e. Angular (corners sharp or irregular)

3. Sand consists of discrete particles of size greater than 0,075 mm but not greater than 2,5 mm. Except for the finer sizes, the particles are visible to the naked eye. Sand is distinguishable by the presence of gritty particles which do not break down when rubbed with water on the palm.
4. Silt consists of discrete particles of size greater than 0,002 mm but not greater than 0,075 mm.
5. Clays consist of particles of size not greater than 0,002 mm.
6. Most natural soils are a combination of one or more of the above types. However, the most important reason for the classification of soils into gravels, sands, silts, and clays relates to the drainage characteristics of the soils.

Further examination of the recovered samples should be performed for moisture condition, colour, consistency, structure, and soil type. The profile observations are frequently carried out on soil cores used for more elaborate laboratory testing (South African Bureau of Standards, 1995).

2.3.2 Interrelation of Soil Profiles and Engineering Design

While the general principles of soil profiling apply in all cases, the engineer responsible for observation in a trial hole will produce more valuable work if the requirements of the proposed design are considered. The engineer should place particular emphasis on those observations which will be of the greatest significance to the design. A single profile may be sufficient for a small design, but for larger structures, such as a road, many profiles may be required (South African Bureau of Standards, 1995). Being able to compare all these trial pits in a GIS context with all the relevant test data and information would improve the engineer’s understanding of the site. The ISGE would be a useful tool for making comparisons of the trial pits.

2.4 Laboratory Testing

During site investigations samples are collected for geotechnical laboratory tests. These tests are essential for assessing soil engineering properties under controlled conditions. Some of these are index tests that help to classify and identify the soil. In contrast, others are performance tests that help engineers estimate soil engineering properties for analysis and design. Some tests could be conducted on a bulk soil sample, which may be disturbed. Exceptions are water content, where the sample must be sealed in an airtight container and unit weight, where the sample must be undisturbed. All performance tests require undisturbed samples (De, 2015). The results from these tests work well with the site investigation information to give a geotechnical engineer a good impression of the soil conditions on a site. Therefore, these tests are also an essential part of the ISGE. The tests, however, must strictly follow the SANS3001 codes, which are standard in South Africa.

2.4.1 Standards

The same types of test methods are used worldwide to a large extent. However, the specified standards must be followed precisely when performing tests since minor differences in the testing procedure can significantly impact the test result—the size and type of samples required depend on the test that is to be carried out. The field samples would usually be reduced into one or smaller laboratory samples (Robinson & Thagesen, 2004).

The SABS provides a range of standards covering the civil engineering industry requirements, from quality management systems to testing methods for specific materials or parts (South African Bureau of Standards (SABS), n.d.). SANS3001 refers to standards that test materials require for civil engineering practice. As the SANS3001 series of test methods are published, they supersede the previously used TMH1 methods (South African National Roads Agency, 2013).

2.5 Classification Tests

Classification tests are relatively cheap and include moisture content, liquid limit, plastic limit, shrinkage limit, linear shrinkage and particle size distribution. The results confirm soil description and quantify variations in the soil profile during the field investigation, both laterally and with depth. Compaction tests are also used to classify construction materials. Soil classification can predict the behaviour of soil and estimate design parameters needed for an engineering design using established correlations. This assumes that all materials falling into a given class will behave similarly. These correlations should be used with caution and only for the material and conditions they produced (SAICE, 2010).

2.5.1.1 Particle size distribution

The general usage of the term for soil describes the deposition of disintegrated rock particles and human-made materials. Owing to large differences in soil behaviour and characteristics, several subdivisions and categories were developed to classify the soil types. In nature, soil particles appear in varying forms and sizes. These physical properties influence soil behaviour. The sizes of soil-forming particles differ across a wide range. Soils are commonly called gravel, sand, silt or clay, depending on the prevailing particle size within the soil (Das, 2017). Soil coarseness or fineness is reflected in terms of the sizes of the particles present in the component; those most considered are gravel, sand, silt and clay. Before discussing these solids in detail, it should be noted that although all international organisations now accept that the most convenient way of defining gravel, sand, silt and clay is based on particle size, different organisations have assigned different values to the relevant sizes.

In 1908 the Swedish soil scientist, Atterberg, published what is perhaps the most significant early attempt to place the limiting sizes of the different soil fractions on a scientific basis. Atterberg defined gravel particles as being between 20 and 2 mm in size, he said these were the limits under which no water is kept between particles in the pore spaces and where water is kept weakly in the pores. The sand was between 2 and 0.2 mm in size. The lower limit was set by capillary action at the point where water is held in the pores.

Atterberg visualised silt as the soil component that ranges in size from where the sand starts assuming clay-like characteristics to the upper limit of the clay itself, i.e. between 0.2 and 0.002 mm. The selection of 0.002 mm as the upper limit of the clay fraction assumed that particles smaller than this exhibited Brownian motion when in aqueous suspension (Boyle et al., 2007).

The particle size distribution indicates the relative proportion (by weight) of particles of different sizes that make up a soil sample. A sieve analysis (whether dry or wet) is commonly used for coarse-grained soils, whereas a hydrometer method is used for fine-grained soils. Particle size distribution may be conducted on a disturbed sample. It is important to ensure that the test specimen is truly representative of the soil, especially when it comes to the particles that are relatively large or small, of which the smaller particles which tend to be easily discarded (De, 2015)**.**

The results of an analysis of the sieve are usually displayed in a graph. The sieve sizes are plotted on the x-axis on a logarithmic scale. The proportions of the soil sample passing the corresponding sieves by mass are plotted as the y-axis on an arithmetic scale. A well-graded soil is one with a slightly sloping sieve curve, indicating that the soil has a wide range of particle sizes. One with a predominance of single-sized particles is uniformly graded soil while a gap-graded soil lacks a range of particles of one size. The uniformity coefficient is often used as a single numerical representation of the particle-size distribution for concise correspondence. The coefficient is defined as the ratio of the sieve size by which 60% of the material passes through to that of the sieve size by which 10% passes through. (Robinson & Thagesen, 2004).

The grading of material indicates important qualities of a material such as the following:

- Maximum particle size requirements
- Relative distribution of particle sizes
- Amount of fine material present, which can affect compactibility and permeability.

Testing for gradation involves determining percentages of the different grain sizes present in soil from two test processes: sieving and sedimentation. Two sieving methods are specified, namely dry sieving and wet sieving if the sample contains silt or clay. Only sedimentation tests will assess the relative proportions of the silt and clay. (South African National Roads Agency, 2013).

2.5.1.2 Mechanical analysis

Mechanical analysis is used to determine the size range of particles found in a soil, expressed as a percentage of the total dry mass.

The following two techniques are typically used to determine soil particle size distribution:

- Sieve analysis - for particle sizes greater than 0.075 mm in diameter and
- Hydrometer analysis - for particle sizes smaller than 0.075 mm in diameter. (Das, 2017).

Sieve analysis consists of shaking the soil sample through a series of sieves with gradually smaller openings. The sieves used for soil analysis usually have a diameter of 203 mm. To examine the sieve, the soil must first be oven-dried, and then all the lumps split into tiny particles. The soil is then shaken through a stack of sieves with openings from top to bottom, decreasing in size (a pan is placed below the stack). The mass of soil retained on each sieve will be determined after the soil has been shaken. When studying cohesive soils, it can be challenging to split the lumps into individual particles. In this case, to make a slurry, the soil can be mixed with water and then washed through the sieves. Portions retained on each sieve are collected separately and oven-dried before measuring the retained mass on each sieve. (Das, 2017).

2.5.1.2.1 Dry sieving (SANS3001 – GR1)

This part of the SANS 3001 aims to obtain results intended for the primary classification of materials and to determine the conformity of particle size distribution to the applicable specifications. The data obtained could also be useful in the development of relationships among packing (compaction), interlocking ability (densification), and material blending. Although it follows the principles of the test methods ASTM and BS, this part of the SANS 3001 differs from them in the following ways (South African Bureau of Standards (SABS), 2011):

- It prescribes the use of a sieve of 75 μm instead of a sieve of 63 μm;
- It does not include the determination of the fractions of silt and clay; and
- It provides for the separation of fines for use in the Atterberg limits test.

Dry sieving is only suitable for soils that contain negligible quantities of silt and clay, i.e. essentially cohesionless soils (Boyle et al., 2007). Nevertheless, many laboratories practise dry sieving of unwashed samples. The fines tend to stick to the coarsest particles in some tropical soils. Therefore, dry sieving should only be permitted if it has been shown that the same results are obtained as with the wet sieving or the sieving of washed samples. The sieves may be shaken by hand;

however, a mechanical shaker ensures more reliable results. (Robinson & Thagesen, 2004).

2.5.1.2.2 Wet sieving (SANS3001 – GR2)

This test method is used to determine the particle size distribution of materials proposed for use as gravels and sands. The results are used for rapid determinations during construction control processes, particularly crushing. The method is also applicable for sand with little or no cohesion or with aggregates without fines. Wet sieving includes the quantitative determination of the distribution of particle size down to fine sand size: this involves the preparation of a specified volume of soil and the washing of all silt and clay through a specified sieve (Boyle et al., 2007) Please make these changes in the rest of the document

2.5.1.3 Particle size distribution curve

The percentages of particles present in a soil from the particle-size distribution curve can be derived from gravel, sand, silt, and clay. Thus, particle size distribution shows the range of particle sizes present in a soil and the type of distribution of particles of various sizes.

If the size range is high, the gradation curve will be steep, and the soil will be defined as uniform soil. A poorly graded soil in its gradation u-curve may have a near-horizontal hump, suggesting that it lacks specific intermediate sizes. This is a gap-graded soil. When used for soil classification purposes, the findings of particle size distribution tests are of great importance. (Boyle, et al., 2007).

2.5.1.4 Hydrometer analysis (SANS3001 – GR3)

This section of SANS 3001 is used to calculate the particle size distribution of graded materials when silt and clay fraction information are required. The results are used to classify materials and determine whether the particle size distribution complies with applicable standards (South African Bureau of Standards (SABS), 2014).

The hydrometer method calculates the density of the soil-water mixture using a relative density hydrometer at fixed-time intervals. It then calculates the distribution of particle sizes by formula measurement or nomograph. (Boyle, et al., 2007).

Analysis of the hydrometer is based on the principle of soil grain sedimentation in water. When a soil specimen is dispersed in water, the particles settle at various velocities, depending on their shape, size, weight and water viscosity. It is assumed that all soil particles are spheres and that Stokes' law can express the velocity of soil particles. (Das, 2017).

2.5.2 Moisture Content

Originally developed and used by agricultural research workers, this part of the SANS 3001 has been in use in South Africa for more than 60 years as part of other methods published in TMH1 standard methods for testing road construction materials. (South African Bureau of Standards (SABS), 2012). The moisture content of a material is measured using the SANS 3001-GR20, namely oven-drying assessment of the moisture content. The test consists of determining the mass of a sample before drying it in a tared container. The sample container is put in a forced draft-type oven set between 105 and 110 °C. and dried to constant weight (usually overnight). The container mass, along with the sample, is then again determined. The moisture content is measured using the difference in the moist and dried material mass, expressed as a percentage of the dry material mass. (South African National Roads Agency, 2013).

The engineering properties of a soil, such as the characteristics of strength and deformation, depend on the number of voids and water in the soil to a degree. It is usually expressed as a percentage, although, in most calculations, the decimal fraction is used. (Robinson & Thagesen, 2004).

2.5.3 Atterberg Limits (Plasticity)

When clay minerals occur in fine-grained soil, the soil can be remoulded without crumbling in the presence of some moisture. The adsorbed water surrounding the clay particles creates a compact shape. A Swedish scientist named Atterberg developed a method in the early 1900s to describe the consistency of fine-grained soils with varying moisture content. Soil acts more like a solid at a very low moisture content. When the moisture is very high, the soil and water may flow like a liquid. Therefore, the actions of the soil can be arbitrarily divided into four basic states, namely solid, semi-solid, plastic and liquid. (Das, 2017).

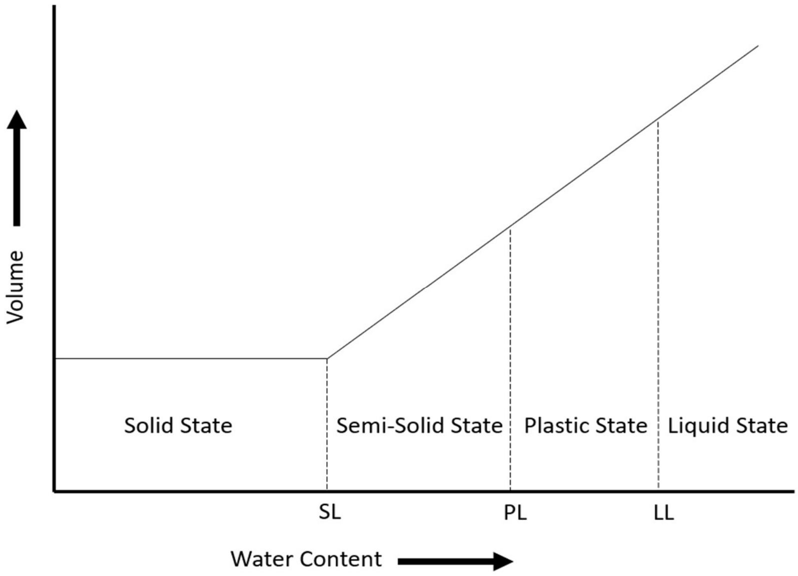


Figure 1 – The different states of soil

In general, a soil may exist in one of the liquid, plastic, semi-solid and solid states depending on its water content (defined as the ratio of the mass of water in the soil to the mass of solid particles). If a soil's water content is gradually reduced initially in liquid state, the state will change from liquid through plastic and semi-solid, accompanied by a gradually decreasing volume until the solid state is reached. The contents of water at which the transitions between states take place differ from soil to soil. Many fine soils remain in the plastic condition in the field. Plasticity is due to the presence of a large amount of mineral clay (or organic material) particles in the soil. The void space between these particles is typically very small because of capillary tension retaining water at negative pressure. It produces a degree of cohesion among the particles, allowing for deformation or moulding of the soil. Absorption of water can lead to plastic behaviour due to surface forces on clay mineral particles. Any reduction in water content results in a decrease in the thickness of the cation layer and an increase in the net attractive forces between the particles. (Craig, 2005).

Atterberg limits refer to the limits of liquid (LL), plastic limits (PL) and linear shrinkage (LS). The LL and PL difference is the plasticity index (PI). The limits represent moisture content values at which soil behaviour changes. Of interest is the liquid limit which is the moisture content at which the soil behaviour changes from a plastic to a liquid state, and the plastic limit, which is the moisture content at which the soil behaviour changes from a semi-solid to a plastic environment. The plasticity index is the range of moisture content in which the soil remains in a plastic condition; that is, without substantial cracking (not becoming brittle), the soil can undergo deformations. For this test, it is not important to preserve the sample against its natural moisture content. Atterberg limit test results (LL, PL, and PI) are used to classify fine-grained soils, such as clay and silt. The Casagrande plasticity chart is helpful for this purpose. Atterberg limits are also soil behaviour indicators and are often used in correlation with other soil properties, such as resistance, compressibility, and liquefaction potential. (De, 2015).

Nevertheless, when the soil is dried until testing, the plasticity of certain tropical soils decreases. Therefore, avoiding drying the sample and using wet preparation of the test specimens may be necessary. Other soils may contain weak aggregations due to break downs when mixed intensely with increase in plasticity. This often calls for wet preparation since less mixing is involved in this procedure than dry preparation. (Robinson & Thagesen, 2004).

2.5.3.1 Liquid limit

The liquid limit is the water content at which the soil transitions from the liquid state to a plastic state. It is measured by spreading a portion of the soil sample in the brass cup of a Casagrande device and dividing it using a grooving tool. The moisture content when the groove closes a certain range of drops (taps) of the cup is recorded as the liquid limit of that soil.

2.5.3.2 Plastic limit

At the point of transition from semi-solid to plastic, the moisture content is classified as the plastic limit. The plastic limit is specified as the percentage of moisture content at which the soil crumbles when rolled into 3mm-diameter threads. The plastic limit represents the lower limit of the soil plastic level. The plastic limit test is simple and is carried out by hand on a ground glass plate by repeated rolling of an ellipsoidal-sized soil mass. As in liquid limit determination, the plastic limit can be obtained using the fall cone process. (Das, 2017).

2.5.3.3 Plasticity index

The plasticity index (PI) is the difference between a soil's liquid limit and its plastic limit. (Das, 2017).

2.5.3.4 Linear Shrinkage

Linear shrinkage is the decrease in length of a soil sample when dried, that starts with a moisture content equivalent to the liquid limit that decreases in one dimension expressed in percentage of the original dimension of the soil sample. (Das, 2017).

2.5.3.5 SANS3001 Standard tests for Atterberg limits

These test methods usually are performed on material that passes the 425 µm sieve and on material that passes the 75 µm sieve when required. The results of the test on material that passes the 75 µm sieve should be clearly defined to prevent misunderstanding (SABS,2013).

Depending on the necessity, the linear shrinkage test is performed either on the material passing the 425 µm sieve or on the material passing the 75 µm sieve.
The flow curve liquid limit test method given in the SANS 3001-GR12 is recommended for materials where a plasticity index greater than 20 is required instead of the one-point method provided in the SANS 3001-GR10 or the two-point test method provided in the SANS 3001-GR11. (South African Bureau of Standards (SABS), 2013d).

The liquid limit and plastic limit test methods are similar to the ASTM and BS test methods, except that the volume of material measured varies. The ASTM and BS test methods integrate the material extraction from the field sample to shape the test sample. The BS method's plasticity index value is approximately four units higher than that produced from the ASTM method. The ASTM shrinkage test method tests volume alteration only, while the BS test method tests volume alteration and linear shrinking.

2.5.3.6 Activity

Since soil plasticity is caused by the adsorbed water covering the clay particles, clay minerals and their relative concentrations in a soil may be expected to affect the liquid and plastic limits. Skempton (1953) observed that a soil's plasticity index rises linearly with the percentage of clay-size fraction present (percentage finer than 2 mm by weight). The PI correlations with the clay-sized fractions plot separate lines for various clays. This disparity is due to the complex plastic properties of the various types of clay minerals.

Based on these tests, Skempton specified a quantity called activity, which is the slope of the line that correlates PI and is less than 2 mm percent finer (Das, 2017).

2.5.3.7 Plasticity Chart

Casagrande studied the plasticity index in relation to the liquid limit of a wide range of natural soils (Casagrande, 1932). He suggested a plasticity chart based on the test results. The essential characteristic of this chart is the empirical A-line. The inorganic clays are distinguished from inorganic silts by an A-line. Inorganic clay values are above the A-line while inorganic silts are slightly below the A-line. Organic silts plot in the same area (below the A-line and LL varying from 30 to 50) as medium compressible inorganic silts. Organic clays are plotted in the same area as extremely compressible inorganic silts (below the A-line and liquid limit above 50). The information given in the plasticity chart is of great importance and is the basis for the unified soil classification system (USCS) classification of fine-grained soils. Note that above the A-line lies a line called the U-line. The U-line for any currently defined soil is approximately the upper limit of the plasticity index relationship to the liquid limit.

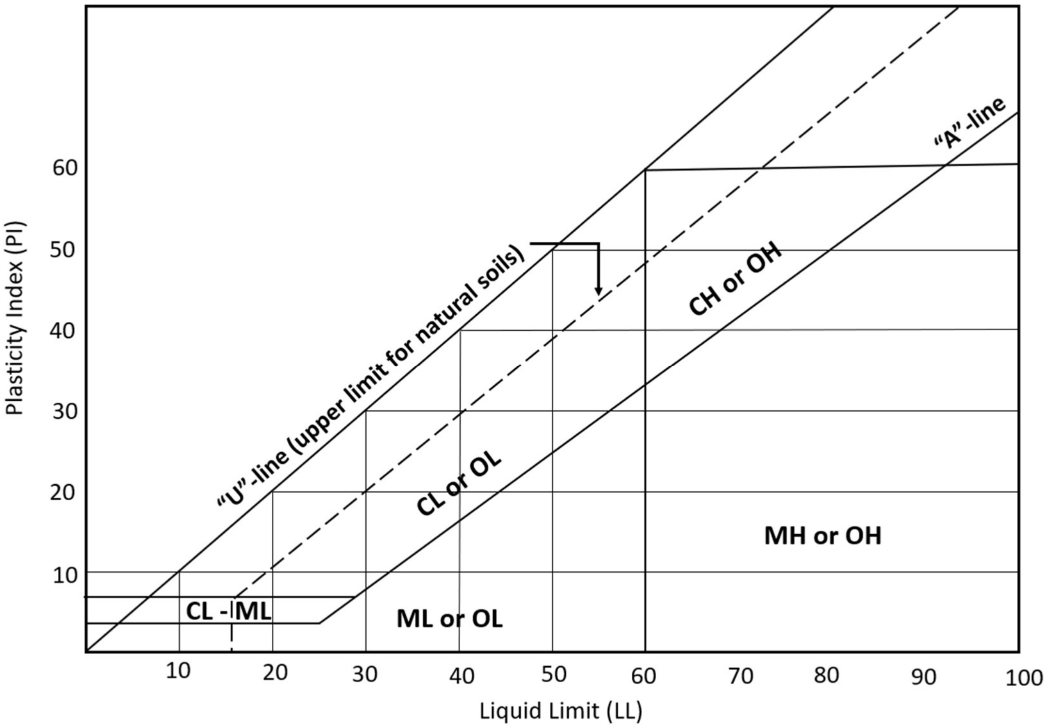


Figure 2 - Plasticity chart (Casagrande, 1932)

The A-line and the U-line have another use. Casagrande suggested that a soil's shrinking limit can be approximately determined if its plasticity index and liquid value are known (Das, 2017).

2.6 Compaction

In general, compaction is soil densification by removing air. This requires mechanical energy. Loose soils must be compacted to increase their unit weights when constructing highway embankments, earth dams, and many other engineering structures. Compaction increases soil strength characteristics, thereby increasing the bearing ability of the foundations built over them. Compaction also decreases the amount of undesirable structural settling and increases the stability of embankment slopes. The weight of its dry unit measures the degree of a soil's compaction. When water is applied to the soil during compaction, it acts on the soil particles as a softening agent. The particles in the soil slip over each other and push into a tightly packed location. After compaction, the dry unit weight increases first as the moisture content increases (Das, 2017).

Beyond a certain moisture content, any change in the moisture content tends to decrease the weight of the dry unit. This phenomenon occurs because the water takes up the spaces which the solid particles would have occupied. In general, the moisture content at which the maximum dry unit weight is reached is referred to as the optimum moisture content. The laboratory test generally used to get the maximum compaction weight of the dry unit and the optimum moisture content is the compaction test (Das, 2017).

In 1933 Ralph Proctor introduced what became known as the Proctor test, whereby material was compacted in three layers in a standard steel mould 100 mm in diameter using a standard hammer. The highest density achieved after varying the moisture content of the material is calculated as a dry density. It is known as the maximum dry density of the material in question. The moisture content required for the specified Proctor compactive effort to achieve this density is known as the optimum moisture content (South African National Roads Agency, 2013).

The compactive effort is meant to be the equivalent of a medium-sized field roller. Modified compaction represents more precisely what can be obtained successfully in the field, but standard values are widely used, especially for subgrades. For a range of different soil moisture contents, the compaction test is repeated. The dry density achieved is recorded for each test. The related moisture content and dry density values are then plotted in a diagram, and the points attached to a smooth curve.

The compaction curve usually has a prominent peak, suggesting an optimal moisture content at which the total dry density for a specific compaction effort will be reached. However, the optimum moisture content is not constant for different materials. The optimum content of moisture depends on compaction effort and compaction method, as well as the type of soil. A greater compactive effort results in a higher average dry density at a lower optimum humidity level for the same soil. For example, gravelly soils have a higher average dry density and a lower optimum humidity content than clayey soils for the same compactive effort.

This test is still used in constructing dam earthworks but was superseded by a similar type of test in the road building industry. In a larger 150 mm diameter mould, a much greater compactive effort is applied to the material in three layers. Maximum dry density and optimum values of the moisture content are determined the same way. This was commonly referred to as the density (Mod), or modified AASHTO. However, the correct term is the maximum dry density (MDD), and the test is generally used to control soil and gravel compaction in the field.

The SANS 3001-GR30 test (South African Bureau of Standards (SABS), 2015) for maximum dry density (MDD) and optimum moisture content (OMC) serves the following two distinct purposes:

a. The OMC is the moisture content at which specimens are compacted for other tests, such as CBR, unconfined compressive strength and indirect tensile strength tests, and is an indicator of the best moisture content for compacting materials in the field.
b. The MDD provides a means of comparing field compaction to standard compaction level (percentage of MDD). Thus, MDD provides an indication of the maximum density with standard compactive effort when compacted at OMC.

By achieving higher densities, the shear strength and elastic modulus are improved, resulting in a lower tendency for additional traffic-related compaction and consequent rutting under traffic while also reducing pavement deflection under wheel loads (South African National Roads Agency, 2013).

2.6.1 California Bearing Ratio SANS3001 – GR40

Penetration tests such as the California bearing ratio (CBR) test largely measure the soil's resistance to shearing deformation. The CBR test is more flexible than many other penetration tests, and it can be performed on almost all materials, from clay to gravel (South African National Roads Agency, 2013).

Usually, the CBR test is done in the laboratory. The underlying principle of the test involves determining the relation between force and penetration when a standard cross-sectional area cylindrical plunger is made to penetrate a compacted soil sample at a given rate. At some penetration values, the ratio of the applied force to a standard force, expressed as a percentage, is defined as the soil's California bearing ratio (CBR) (Boyle, et al., 2007).

The CBR test (SANS 3001-GR40) is carried out on compacted specimens of the material for gravels and soils of G4 and lesser quality. The material is scalped onto the 37.5 mm sieve, as in the MDD/OMC test case, and the oversize is discarded.

A material's CBR is an indirect measure of shear resistance or bearing capacity under a single charge. Owing to the different properties in natural materials (grading, plasticity), significant variations in CBR values can occur even on a split sample. Overall, the higher the force, the greater the variations. Therefore, these should never be based upon a single value when applying CBR standards for a material. Wherever possible, at least three values should be obtained.

The preparation method in the SANS 3001–GR40 differs from that in the older TMH1 Method A7, where the material was screened through the 19.0 mm sieve, with any material held on this sieve being slightly crushed to pass it. Instead, the test specimen is simply scalped at 37.5 mm for the SANS 3001–GR40 method, and the oversize is discarded.

The CBR test is used to evaluate the strength of bearings of aggregates used in sub-base and base layers. As part of this test, the CBR swell is also determined and indicates volume changes when the material is soaked. (South African National Roads Agency, 2013) Apart from minor method variations, it is similar to the ASTM and BS test methods (South African Bureau of Standards (SABS), 2013e).

2.6.2 Classification of Soils

Depending on the predominant size of particles inside the soil, soils are generally called gravel, sand, silt, or clay. Several organisations have developed particle-size classifications to classify soils by their particle size. Based on their engineering behaviour, different soils with similar properties can be divided into classes and subgroups. Classification systems provide a popular language for describing concisely, without detailed explanations, the general characteristics of soils, which are infinitely complex. Most of the soil classification systems developed for engineering purposes are based on simple indexing properties such as distribution and plasticity of particles. While several classification systems are now used owing to the wide variety of soil properties, none is fully conclusive on any soil for all possible applications. Both systems take the particle-size distribution and Atterberg limits into consideration. They are the American Association of State Highway and Transportation Officials (AASHTO) classification system and the unified soil classification system (USCS). The classification system AASHTO is mainly used by the departments of the state and county highways while geotechnical engineers generally prefer the USCS (Das, 2017). South Africa has also developed its own COLTO grading system. All three of these classification methods would be useful for the ISGE, as classifying soils is important in both understanding soils and making informed decisions about the soil.

In South Africa, the TRH14 (COLTO) classification system is regularly used. The other systems (AASHTO and UCSC) are also regularly used globally but are less frequently used in South Africa.

2.6.2.1 AASHTO classification system

In 1929 the soil classification system AASHTO (as shown in Table 5) was established in the United States of America as the classification system for the Public Roads Administration. It has undergone some revisions, with the present version introduced in 1945 by the Highway Research Board's Committee on Classification of Materials for Subgrades and Granular Type Roads (Das, 2017).

Table 5 - AASHTO classification

General Classification			Granular Materials (35% or less passing 0.075)					Silt-Clay Materials (more than 35% passing 0.075mm)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5, A-7-6
Sieve analysis per cent passing											
2.00 mm (No. 10)	50 max.	-	-	-	-	-	-	-	-	-	-
0.425 mm (No. 40)	30 max.	50 max.	51 max.	-	-	-	-	-	-	-	-
0.075mm No. 200)	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing 0.425mm (No. 40)											
Liquid limit	-		-	40 max	41 min.	40 max	41 min.	40 max	41 min.	40 max	41 min.
Plasticity index	6 max.		NP[a]	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.[b]
Usual types of significant constituent materials	Stone fragments, gravel, and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good							Fair to poor			

[a] NP, nonplastic

[b] Plasticity index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity index of A-7-6 subgroup is greater than LL minus 30

2.6.2.2 Unified soil classification system

In 1942, Casagrande suggested the original form of this system for use in constructing airfield works performed by the Army Corps of Engineers during World War II. In coordination with the USA, this programme was revised by the Bureau of Reclamation in 1952 as shown in Table 6 below. Now it is commonly used by engineers (Das, 2017).

Table 6 - Unified soil classification system

COARSE GRAINED SOILS (MORE THAN 50% > 0.075 SIEVE)	**GRAVELS** (MORE THAN 50% > 4.75 SIEVE)	> 5% FINES	$C_u \geq 4$ and $1 \leq C_c \leq 3^c$	GW	GRAVEL (WELL GRADED)
			$Cu < 4$ and/or $Cc < 1$ or $Cc > 3^c$	GP	GRAVEL (POORLY GRADED)
		> 12% FINES	*PI* < 4 or plots below "*A*" line	GM	SILTY GRAVEL
			PI > 7 and plots on or above "*A*" line	GC	CLAYEY GRAVEL
	SANDS (MORE THAN 50% < 4.75 SIEVE)	> 5% FINES	$Cu \geq 6$ and $1 \leq Cc \leq 3^c$	SW	SAND (WELL GRADED)
			$Cu < 6$ and/or $Cc < 1$ or $Cc > 3^c$	SP	SAND (POORLY GRADED)
		> 12% FINES	*PI* > 4 or plots below "*A*" line	SM	SILTY SAND
			PI > 7 and plots on or above "*A*" line	SC	CLAYEY SAND
FINE GRAINED SOILS (MORE THAN 50% **<** 0.075 SIEVE)	**SILTS & CLAYS** L.L < 50		*PI* > 7 and plots on or above "*A*" line (Figure 4)^e	ML	SANDY SILT
			PI < 4 or plots below "*A*" line	CL	SANDY CLAY
			$\frac{\text{Liquid limit—oven dried}}{\text{Liquid limit—not dried}} < 0.75$ See Figure 4; OL zone	OL	ORGANIC SILTS & CLAYS (SANDY)
	SILTS & CLAYS L.L > 50		*PI* plots on or above "*A*" line	MH	SILT
			PI plots below "*A*" line	CH	CLAY
			$\frac{\text{Liquid limit—oven dried}}{\text{Liquid limit—not dried}} < 0.75$ see Figure 4; OL zone	OH	ORGANIC SILTS & CLAYS
	HIGHLY ORGANIC SOILS		Primarily organic matter, dark in colour, and organic odour	PT	PEAT

a Gravels with 5 to 12% fine require dual symbols: GW-GM, GW-GC, GP-GM, GP-GC.
b Sands with 5 to 12% fines require dual symbols: SW-SM, SW-SC, SP-SM, SP-SC.
d If 4 _ PI < 7 and plots in the hatched area, use dual symbol GC-GM or SC-SM.
e If 4 _ PI < 7 and plots in the hatched area, use dual symbol CL-ML.

2.6.2.3 TRH14 - COLTO classification

In the TRH14 system (shown in Table 7), the untreated or granular materials are classified as follows:

- Graded crushed stone (G1, G2, G3)

- Natural gravels, including modified and processed gravel (G4, G5, G6)
- Gravel-soil (G7, G8, G9, G10)

Table 7 – TRH14 -COLTO grading

Summary of Classification System for Construction Earthworks Materials (ref. COLTO)													
Material Group	Graded, Crushed Stone			Natural Gravels			Gravel Soil			Cementitiously Stabilised Materials			
Material Class	G1	G2	G3	G4	G5	G6	G7	G8	G9	C1	C2	C3	C4
Description	Crushed sound rock with parent material fines	Sound rock/coarse gravel + addition of approved fines up to: 10%	15%	Natural gravel or natural gravel and boulders may be mechanically modified or mixed with crushed rock			Natural material (soil, sand or gravel)	Natural material (Soil, sand or gravel) See below for properties		at least G2	at least G2/G3/G4	at least G5/G6	
GRADING (Table: 3402/1-2; 3602/1-3)													
Nominal Aperture size of sieve(mm)	Nominal max. size 37.5mm (% passing)	Nominal max. size: (% passing) 37.5mm	28.00mm	Natural Gravel*same as G1 for crushed stone						Aggregate Quality Before Stabilisation: Nominal Maximum size of Aggregate (%passing) 37.5mm/28.mm		See G5/G6	
37.5	100	100		85 - 100	(1) Uncrushed: max 63 mm (2) Crushed: max 53 mm (unless otherwise specified)	1)Uncrushed: max 2/3 of compacted layer (2)Crushed: max 63 mm(unless otherwise specified)	Max. size shall not be greater than 2/3 of the layer thickness, or 75 mm for crushed material	Nominal maximum size shall not exceed 2/3 of the compacted layer thickness		Untreated material characteristics shall comply with the relevant applicable grading specification i.e. G1,G2,G3 or G4		Maximum size in place after compaction should not exceed two-thirds of the compacted layer thickness, or 63 mm, whichever is the smaller	
28.0	86 - 95	86 - 95	100	–									
20.0	73 - 86	73 - 86	87 - 96	61 - 91									
14.0	61 - 76	61 - 76	73 - 86	–									
5.0	37 - 54	37 - 54	43 - 61	31 - 66									
2.0	23 - 40	23 - 40	27 - 45	20 - 50									
0.425	11 - 24	11 - 24	13 - 27	10 - 30									
0.075	4 - 24	4 - 24	5 - 12	5 - 15									
Grading Mod (min)	n/a			n/a	1.5 - 2.5	1.2 - 2.6	0.75 - 2.7	0.75 - 2.7		*GM for Base ≥ 1.75&Sub-Base ≥ 1.50			
Flakiness Index	Max.35% on weighed avg. of 28mm and 20mm fractions			as for G1 - G3	n/a		n/a	n/a		Max 35% : as for G1-G4		n/a	
Crushing Values (strength)	10% FACT (min) 110-200 kN and ACV(max) 21-29%-see Table 3602/2 and 3			n/a			n/a	n/a		10% FACT(min) 110kN and ACV(max) 29%		n/a	

Table 8 - COLTO grading Atterberg limits

Material Group	Graded, Crushed Stone			Natural Gravels			Gravel Soil			Cementitiously Stabilised Materials			
Material Class	G1	G2	G3	G4	G5	G6	G7	G8	G9	C1	C2	C3	C4
Liquid limit(max)	25	25		25	30	n/a	n/a	n/a		PI After Treatment (3402/5)			
Plasticity Index, PI(max)	5	6		6	10	12 or 2 x GM +10	12 or 3 x GM +10	12 or 2 x GM +10		slightly plastic	slightly plastic	6 max	6 max
Linear shrink,%(max)	2	3		3	5	5	n/a	n/a		*Stabilizing agent: max 5%			
BEARING/DESIGHN STRENGTH AND SWELL (Table: 3402/1, 2, 5; 3602/2 - 3)													
CBR%(min) at MDD	*Please see "Crushing Values"			80 at 98%	45 at 95%	25 at 95%	15 at 93%	10 at in situ	7 at in situ	min G2	min G4	min G6	min G6
Swell%(max) at MDD	n/a	n/a		0.2 at 100%	0.5 at 100%	1.0%	1.5%	1.5%	1.5%	n/a	n/a	n/a	n/a
UCS(Mpa)100%@MDD	–	–	–	–	–	–	–	–	–	6 - 12	3 - 6	1.5 - 3	0.75 - 1.5
UCS	–	–	–	–	–	–	–	–	–	4 - 6	2 - 4	1 - 2	0.5 -1
ITS	–	–	–	–	–	–	–	–	–	–	–	250 min	200 min
Material Class	G1	G2	G3	G4	G5	G6	G7	G8	G9	C1	C2	C3	C4

SAMPLE/TESTING GUIDELINES													
Specimen /Test Type	COLTO Classification	Sieve Analysis	Mod AASHTO	Mod AASHTO & CBR	Mod AASHTO & UCS	Mod AASHTO, UCS & ITS	ICC/ICL	Moisture content	UCS Design	Asphalt Marshall	Asphalt BC & Grading	Concrete Mix Design	Fresh Concrete Sample
Min sample size	80 kg	±3 kg	±50 kg	80 kg	80 kg	100kg	5 kg	1.5 kg	320 kg	25 kg	5 kg	210 kg	301
Estimated testing duration	7 days	3 days	2 days	7 days	7 days	5 days	2 days	2 days	10 days	4 days	2 days	35 days	29 days

2.7 Geotechnical Tests Not in SANS3001

The consolidation, direct shear and triaxial tests are the only tests that should be part of the ISGE but do not have SANS3001 or South African-specific standards. They are standard geotechnical tests that are regularly used in South Africa and therefore should be implemented for their applications and their usefulness in assessing soils. These tests rather make use of developing South African protocols or standard methods that produce results that can be used in a South African context (e.g., metric units should be used and should apply to South African soils).

2.7.1 Consolidation

When a saturated layer of soil is exposed to an increase in stress, pore water pressure suddenly increases. In highly permeable sandy soils, the drainage caused by increased pore water pressure is immediately completed. Pore water drainage is followed by a decrease in soil mass volume, which results in settlement. Elastic settlement and consolidation occur concurrently owing to the rapid draining of the pore water in sandy soils. The elastic settlement occurs immediately when a saturated compressible clay layer is subjected to an increase in stress. Owing to the considerably smaller hydraulic conductivity of clay than sand, the excess pore water pressure produced by loading gradually dissipates over a long period. The related volume shift (the consolidation) in the clay continues long after the elastic settlement. The settlement in clay caused by consolidation can be many times larger than the elastic settlement. Terzaghi had first suggested the one-dimensional consolidation testing procedure (Das, 2017).

The compressibility of saturated cohesive soils is estimated using the laboratory consolidation test with low hydraulic conductivity. The test is performed on the oedometer in which a saturated, cylindrical soil specimen is laterally confined within a metal ring. Normal stress is applied in the direction of the axis, and the specimen can axially compress without any change in its lateral dimension. The specimen must always be kept under saturated condition during the test.

The specimen's axial displacement is measured over time while the normal stress is held constant. As the specimen consolidates, the axial displacement occurs accompanied by the dissipation of excess pore water pressure. At first, the rate of displacement is rapid and then slows, eventually becoming asymptotic. If consecutive readings show no change in axial displacement with time, the next increase in load may be applied, and the same procedure followed. The range of normal stresses applied during the test is selected based on in situ stress conditions and the maximum stress expected at the stratum where the sample was collected (after construction). The load is reversed in a typical test to incorporate an unload-reload cycle during a consolidation test. From this, slopes are obtained of both the virgin compression and recompression portions of the consolidation curve. At the point of inflexion of the consolidation curve, the value of maximum past pressure, s’ (also known as the pre-consolidation stress, or yield stress), can be estimated using a graphical construction method. The consolidation coefficient from the time of consolidation curves can be calculated based on additional graphical methods. An undisturbed sample is essential for a consolidation test. The transition from recompression to virgin compression portions of the curve is affected by sample disturbance. A reliable value for the maximum past pressure cannot obtain s' without good quality, undisturbed samples (De, 2015).

When an embankment is placed on a saturated soil mass, the immediate tendency is to push the particles closer together in the foundation material. However, the water in the soil, being incompressible, must initially carry part of the load applied, resulting in an initial pressure being produced, i.e., the pore water pressure, which continues as water drains from the soil. As a result, the soil particles are constantly forced closer during the drainage period, taking many years to finish, thus producing the volume change called settlement. One-dimensional consolidation tests try to estimate both the rate and total settlement amount of a soil layer under an applied load in an accelerated manner.

The standard dead-weight oedometer test (incremental loading) is limited to representative samples of saturated clay, fine silts and other low-permeability soils. The test involves cutting and trimming a soil sample to fit into a special metal ring used in the test and placing the assembly in a loading unit after ceramic porous discs have been placed above and below the sample. For example, in stiff clay, a careful compressive load-unload and reload sequence is then applied with small increments and decreases, and the changes in sample thickness are read at set time intervals. With the continuous oedometer loading test, stresses, strains or pore pressures are varied continuously instead of applying the loads in discrete increments, as in the standard test (Boyle et al., 2007).

2.7.2 Direct shear

The shear strength of a soil mass is the internal resistance per unit area that the soil mass can resist failure and slide along any plane within the sample. To analyse soil stability problems, such as bearing capacity, slope stability, and lateral pressure on earth-retaining structures, one must understand the nature of shearing resistance. Direct shear testing is the oldest and simplest type of shear test arrangement. The test equipment consists of a metal shear box in which the soil specimen is placed. The box is divided into halves horizontally. The normal force is applied from the top of the shear box onto the specimen. Shear force is applied to induce failure in the soil specimen by shifting one half of the box relative to the other. The shear test can be either stress-controlled or strain-controlled according to the equipment. The shear force is applied in equal increments in stress-controlled tests before the specimen fails. The loss occurs along the shear box dividing plane. After applying each incremental load, a horizontal dial gauge is used to measure the shear displacement of the top half of the box. During the test, the change in the height of the specimen (and thus the change in the volume of the specimen) can be derived from the readings of a dial gauge that tracks the vertical movement of the upper charge plate (Das, 2017).

Estimating the shear strength properties of soil is an important requirement of many site characterisation programmes, such as those performed as part of foundation design and construction, slopes, and retaining walls. There are various types of laboratory shear strength tests based on soil type and project needs. Besides these, more specialised tests (such as direct, simple shear, triaxial extension, cyclic triaxial, and true triaxial) are carried out as part of critical projects and for research for specific purposes (De, 2015).

Direct shear box testing is performed only on coarse-grained soils. This is because samples of coarsely grained soils are easier to prepare for shear box testing than triaxial testing. However, with this form of testing, drainage conditions cannot be controlled, nor pore pressures determined, and the nature of the test fixes the shear plane (Boyle et al., 2007).

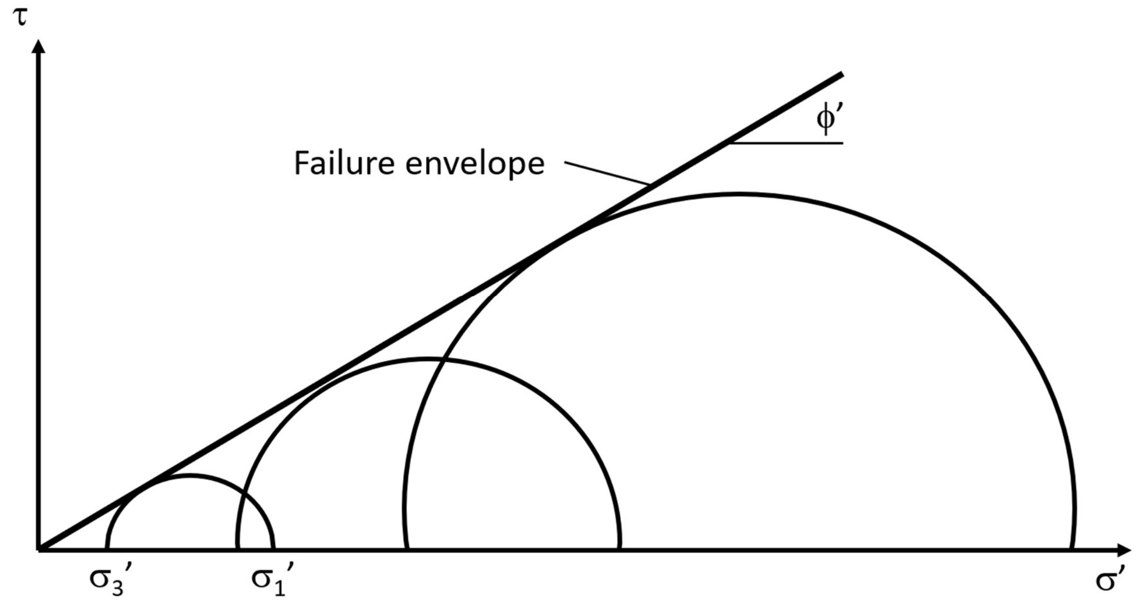


Figure 3 - Stress conditions

The parameters of shear strength are then obtained from the best line which fits the plotted points. The test suffers from several disadvantages, the main one being that it is impossible to control drainage conditions. Since pore water pressure cannot be measured, only the total normal stress can be determined; although if the pore water pressure is zero, this is equal to the effective normal stress. Only an approximation to the pure shear state is produced in the specimen, and shear stress on the failure plane is not uniform, failure progressively occurring from the edges towards the centre of the specimen. The area beneath the shear and vertical loads is not constant throughout the test. The advantages of the test are its simplicity and the ease of specimen preparation in sands (Craig, 2005).

2.7.3 Triaxial shear testing

Triaxial testing is not currently widely used in South Africa. It is likely to become a standard test for granular and stabilised materials. As part of the revision of the South African mechanistic design method (SAMDM), a triaxial test protocol is being standardised (Mgangira, Jenkins, Paige-Green, & Theyse, 2011).

Triaxial compression testing on most soils is the general practice regarding laboratory shear testing. The tests may be unconsolidated undrained or drained tests or consolidated undrained or drained tests if consolidated in the apparatus before the testing. The triaxial shear test is one of the most accurate methods available for parameter determination of the shear strength. This is commonly used for research and conventional testing (Das, 2017).

The tests are designed to derive the angle of internal friction and cohesion, which is considered constant for both laboratory and field conditions. In general, sandy soils, with little or no cohesion, develop their shearing resistance through friction. Internal friction is mainly affected by coarse particle shape and is little affected by moisture content; however, it increases rapidly as dry density increases. The bulk of the shear resistance of clay comes from the cohesion between the particles associated with water bonds. The moisture content greatly influences cohesion, i.e., it decreases to a low level at the plastic limit and to almost zero at the liquid limit with increasing moisture. When an unconfined compressive strength test is performed on a natural clay soil sample, the internal friction may be assumed to be equal to zero, and then the c-value is half the compressive force (Boyle, et al., 2007).

A cylindrical specimen is enclosed in a latex membrane in this test and simultaneously loaded in both the lateral and axial directions. The test is composed of two phases. The specimen may be consolidated in the first stage, and the specimen may be loaded to shear failure in the second. The first stage has two options: either the specimen is unconsolidated (U), and no drainage is permitted while loading the specimen, or consolidated (C), whereby excess pore water pressure is permitted to dissipate. The second stage, known as the shear stage, similarly has two options. The first option is when the specimen is not allowed to drain during loading which means that the loading is considered undrained (U). This causes more excess pore water pressure to develop in the soil when the load is applied slowly. The second option is when the load is considered drained (D) and has excess pore water pressure, developed due to shear loading, is allowed to drain completely. Based on combinations of available first and second stages, triaxial tests can be broadly classified as follows:

a. Unconsolidated-undrained (UU)
b. Consolidated-undrained (CU)
c. Consolidated-drained (CD)

2.7.3.1 Unconsolidated-undrained triaxial compression test

The simplest form of triaxial testing is unconsolidated-undrained triaxial compression (UU), which also takes the shortest time to run. However, the results of this test may be misleading and have limited practical applicability, except in plain cases.

The specimen is not allowed to drain in either of the two stages of the test. Therefore, when the confining pressure is applied, the specimen does not consolidate in the first stage. In the second stage, the specimen is sheared under an undrained condition, allowing excess pore water pressure to develop.

Triaxial UU test results are unreliable and can exhibit considerable scattering (Ladd & DeGroot, 2004) due to sample disturbance effects. This test is relatively fast and can generally over-predict shear strength (which tends to decrease when loading the specimen more slowly).

2.7.3.2 Consolidated-undrained triaxial tests

There are two broad types of consolidated triaxial tests, depending on whether the second stage (during shearing) is in undrained or drained condition, hence the names CU and CD.

A specimen is consolidated by allowing it to drain freely whilst applying a confining pressure—the confining pressure to simulate conditions in situ before field loading. The consolidation process allows for the dissipation of excess pore water pressure (created by confining pressure). It is occasionally necessary to apply back pressure to the specimen before shearing so that after consolidation, the specimen has pore water pressure that is representative of field conditions. Back pressure is also used to ensure that negative pore water pressure does not develop while shearing specimens that tend to exhibit dilation (such as dense sand or steep, over-consolidated clay) under relatively low confining stress.

Drainage of the specimen is closed at the end of consolidation to induce undrained charge during the shearing stage. A pore water pressure transducer is usually connected to the drainage line so that pore pressure readings can be obtained while the specimen is being sheared. The axial load is increased whilst the constant confining pressure is maintained. For soft clay testing, a strain rate of 0.5% to 1.0% per hour is recommended. (Ladd & DeGroot, 2004) During the test, values of both drained and undrained shear strength parameters may be obtained when pore water pressure readings are available during shearing.

2.7.3.3 Consolidated-drained triaxial tests

A consolidated-drained triaxial compression (CD) test allows for first stage consolidation. In the second stage, while allowing drainage, the specimen is sheared to keep the excess pore water pressure at zero. This means the shearing must take place at a rate that allows drainage to occur. Drained shear strength properties can be obtained from this test as the excess pore water pressure remains at zero.

A sand-based CD test can be completed in a reasonable amount of time; however, a clay test may take an extremely long time to complete. For example, leakage along drainage lines leads to some practical difficulties, which complicate the results. CD tests are not common for this reason, and CU tests are commonly used to obtain drained and undrained shear strength parameters (De, 2015).

This chapter has defined the fundamentals and requirements of the geotechnical tests that should be implemented for the storage and transformation of the data that will be implemented in the development of the ISGE.

CHAPTER 3: INFORMATION SYSTEM FOR GEOTECHNICAL ENGINEERS

3.1 Information Systems for Geotechnical Engineers

An information system is a general term for software designed to allow the storage, organisation and retrieval of information. For example, a geotechnical engineering database uses segments, or data blocks, as building blocks of the hierarchical model. Within each segment are multiple data pieces known as fields (Ramesh, 1997).

An information system provides information to engineers to make decisions on projects. Figure 4 below shows the structure of a typical information system. Most information systems provide the following functions:

- Integrate information from numerous sources.
- Provide more accessibility to information in summarised form; and
- Compare historical and current information.

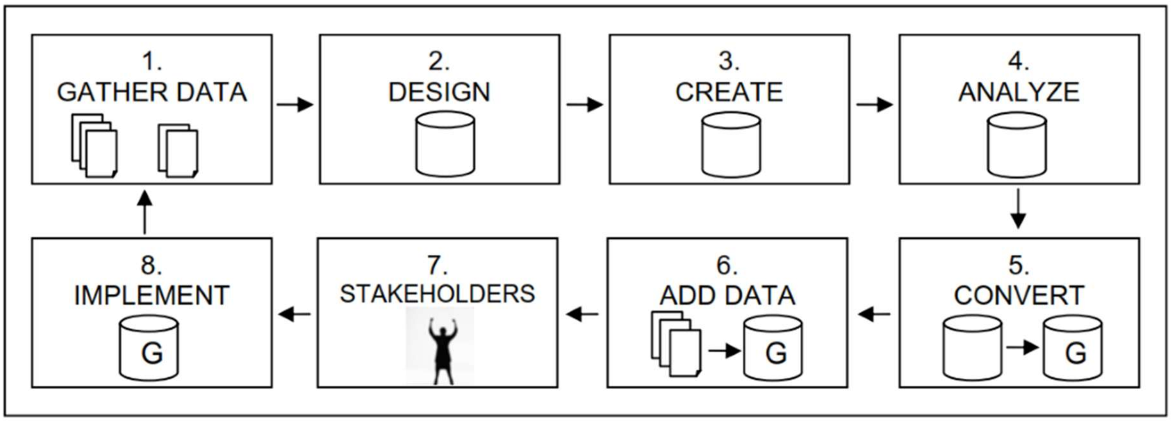


Figure 4 - Typical diagram of an information system for geotechnical engineers (Viljoen, 2006)

The creation of an information system for geotechnical engineers (ISGE) that provides information for the engineer will involve the following processes (adapted from Viljoen, 2006):

i. Gather data from the Geotechnical Engineer (GE) community (stakeholders).
ii. Design the database by indicating which GE entities should be stored. Indicate how the different entities relate to one another.

iii. Create the GE database.
iv. Analyse the GE database.
v. Convert the GE database to a format that can be used in conjunction with the required application.
vi. Add the geotechnical data into the database.
vii. Go back to all the GE stakeholders and determine whether their needs were met and whether changes should be made to the GE database.
viii. Implement the ISGE and make it available to all stakeholders in the GE community.

3.1.1 Important criteria for an ISGE

When creating an ISGE in South Africa, the following would be crucial:

i. The SANS3001 codes in South Africa regulate the most relevant laboratory tests for geotechnical reports. Geotechnical investigations entail the proper use of these codes by an engineer. Therefore, a vital feature of any information system in South Africa should allow the manipulation and storage of data from tests following the SANS3001. The only exceptions are the tri-axial, consolidation and direct shear testing methods which are important tests in South Africa but have no associated SANS codes. These tests should, however, be manipulable in metric units and applicable to South African materials.

ii. An ISGE should be able to store information or data relating the tests to a location. Geographical information systems (GISs) require coordinates or spatial references for the data to be used in desktop studies to assess surrounding areas. Storing this data requires the system to have some form of database capabilities (which will be discussed in the next chapter).

iii. Manipulation is also a key aspect of the system to allow for improved decision making. The data needs to be transformed, summarised, and displayed clearly. Test readings from the database should be transformed into helpful information. This helpful information is classified as anything that gives a more detailed understanding of the results and their implications.

iv. Soil profiles will need to be displayed appropriately according to guidelines given in the SAICE Code of Practice for geotechnical investigations. These guidelines are standard practice in South Africa; this means that most data from sites will use the same format.

v. The ISGE should have the capacity to allow for potential expansion of the database and ISGE interface. In addition, the system needs to allow for more tests to be included in the future to adapt to the rapidly improving software environment. It should be an adaptable system.

3.2 Databases

Databases are organised collections of data stored and accessed electronically through a computer system. Databases need to be designed correctly before they are created, as poor design could lead to failures or major problems in the database itself. To make good decisions, one requires good information derived from raw facts known as data. In this way, data is managed more efficiently in databases. The difference between data and information data is raw facts because they have not been processed to reveal any meaning. Information results from processing the raw data to reveal meaning. This processing could be as simple as revealing patterns or as complex as making forecasts. This information could be used as the basis of decision-making. Raw data should be appropriately formatted for storage, processing, and presentation.

In the current world of information, producing accurate, relevant information is a key part of decision making. Data are the foundation of information that allows an improvement in knowledge. Data management focuses on the proper creation, storage and retrieval of data which should be easily accessible and manageable.
A database is an integrated collection framework for stored data that is centrally managed and controlled. A database typically stores information while avoiding redundancies and supporting a real-time dynamic environment. A database is managed and controlled by a database management system (DBMS). A DBMS is a system software component that is generally purchased and installed separately from other system software components (e.g., operating systems).

A relational database management system (RDBMS) is a DBMS that organizes stored data into structures called tables, or relations. Relational database tables are similar to conventional tables; that is, they are two-dimensional data structures of columns and rows. A DBMS has the following advantages:

1. The system can be expanded, modified or scaled down to easily meet the requirements of its users.
2. It allows better utilization of software which means that it is more economical.

These systems have strong standards that prevent or ensure that formats, naming conventions and documentation are uniform throughout the organization.

Relational database terminology is quite different to conventional table and file terminology. A single row of a table is called a row or record. A column of a table is called and attribute or field. A single cell is called and attribute value or field.
Each table in a relational database must have a unique key. A key is an attribute or set of attributes which occur only once in all the rows of the table. If only one attribute is unique then that key is also called the table's primary key. Primary keys are critical elements of relational database design due them being the basis of relating tables. The keys bind one row from one table to the other key from another table. It connects and binds these tables to each other. (Satzinger, Jackson, & Burd, 2012)

Referential integrity describes a consistent state between the foreign key and primary key values.

3.2.1 Normalization

Normalization is a formal technique for evaluating and improving the quality of a relational database. It determines whether a database is flexible and whether it contains any incorrect types of redundancies. It also defines specific types of methods to eliminate redundancy and improve flexibility. (Satzinger, Jackson, & Burd, 2012)

3.2.1.1 First normal form (1NF)

A table is in first normal form if all the rows contain the same number of columns.

3.2.1.2 Second Normal Form (2NF)

A table is in second normal form if it is in 1NF and if each non-key attribute is functionally dependent on the entire primary key.

3.2.1.3 Third Normal Form (3NF)

A table is in third normal form if it is in 2NF and if no non-key attribute is functionally dependent on any other non-key attribute.

These elements should be implemented into a relational database that will improve the quality of the ISGE as a system that stores and manages information.

3.3 Available Information Systems

Several information systems that transform, store, or visualise geotechnical data have already been developed. Most of these products have been developed in countries outside South Africa. This chapter assesses the features of these available geotechnical Information Systems.

3.3.1 Soil Office

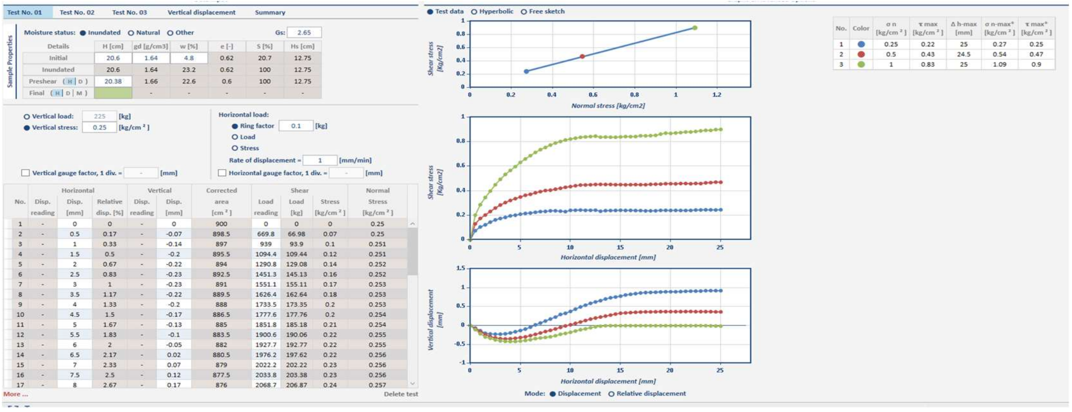
Soil Office is a developer of geotechnical engineering software. The software is developed to be user-friendly and functional with the capacity to perform precise geotechnical calculations. The company has developed several geotechnical software programs which include SO-Sieve, SO-Shear and SO-Log which are applicable information systems. (Soil Office, 2018) These packages have the following features required for an ISGE.

3.3.1.1 SO – Sieve

SO-Sieve includes sieve analysis, hydrometer and Atterberg limits tests. It also presents soils based on the soil type according to the USCS classification. Test results or visual tools can be used to interpret the sieve analysis and Atterberg limits results. The program outputs are presented can be exported in landscape and portrait formats which includes the test data and corresponding calculations (Soil Office, 2018).

3.3.1.2 SO – Shear

The SO-Shear software is aimed at evaluating shear testing (especially direct shear). Test data and corresponding calculations are presented in the interface and the required graphs are shown (Soil Office, 2019).



Moisture status: ● Inundated ○ Natural ○ Other

Gs: 2.65

Details	H [cm]	gd [g/cm3]	w [%]	e [-]	S [%]	Hs [cm]
Initial	20.6	1.64	4.8	0.62	20.7	12.75
Inundated	20.6	1.64	23.2	0.62	100	12.75
Preshear (H | D)	20.38	1.66	22.6	0.6	100	12.75
Final (H | D | M)		-	-	-	-	-

○ Vertical load: 225 [kg]
● Vertical stress: 0.25 [kg/cm ²]
☐ Vertical gauge factor, 1 div. = - [mm]

Horizontal load:
● Ring factor 0.1 [kg]
○ Load
○ Stress
Rate of displacement = 1 [mm/min]
☐ Horizontal gauge factor, 1 div. = - [mm]

	Horizontal			Vertical		Corrected	Shear			Normal
No.	Disp. reading	Disp. [mm]	Relative disp. [%]	Disp. reading	Disp. [mm]	area [cm ²]	Load reading	Load [kg]	Stress [kg/cm ²]	Stress [kg/cm ²]
1	-	0	0	-	0	900	0	0	0	0.25
2	-	0.5	0.17	-	-0.07	898.5	669.8	66.98	0.07	0.25
3	-	1	0.33	-	-0.14	897	939	93.9	0.1	0.251
4	-	1.5	0.5	-	-0.2	895.5	1094.4	109.44	0.12	0.251
5	-	2	0.67	-	-0.22	894	1290.8	129.08	0.14	0.252
6	-	2.5	0.83	-	-0.23	892.5	1451.3	145.13	0.16	0.252
7	-	3	1	-	-0.23	891	1551.1	155.11	0.17	0.253
8	-	3.5	1.17	-	-0.22	889.5	1626.4	162.64	0.18	0.253
9	-	4	1.33	-	-0.2	888	1733.5	173.35	0.2	0.253
10	-	4.5	1.5	-	-0.17	886.5	1777.6	177.76	0.2	0.254
11	-	5	1.67	-	-0.13	885	1851.8	185.18	0.21	0.254
12	-	5.5	1.83	-	-0.1	883.5	1900.6	190.06	0.22	0.255
13	-	6	2	-	-0.05	882	1927.7	192.77	0.22	0.255
14	-	6.5	2.17	-	0.02	880.5	1976.2	197.62	0.22	0.256
15	-	7	2.33	-	0.07	879	2022.2	202.22	0.23	0.256
16	-	7.5	2.5	-	0.12	877.5	2033.8	203.38	0.23	0.256
17	-	8	2.67	-	0.17	876	2068.7	206.87	0.24	0.257

No.	Color	σ n [kg/cm ²]	τ max [kg/cm ²]	Δ h-max [mm]	σ n-max* [kg/cm ²]	τ max* [kg/cm ²]
1	●	0.25	0.22	25	0.27	0.25
2	●	0.5	0.43	24.5	0.54	0.47
3	●	1	0.83	25	1.09	0.9

Figure 5 - SO-Shear (Soil office, 2019)

3.3.1.3 SO – Log

This part of Soil Office package generates boring logs for summary and reporting of several tests performed within a geotechnical engineering project. Boring logs and samples are presented and have laboratory and field test results assigned to them (Soil Office, 2017).

3.3.2 Deep Excavation

Deep Excavation creates design software applications for deep excavation calculations. Triaxial Pro, the only package from Deep Excavation that could be assessed by the ISGE criteria, is a triaxial test data-processing software application. It allows test data to be directly entered from Microsoft Excel and it also allows for automatic linear and non-linear strength estimation and statistical analysis of soil properties from triaxial tests. (Deep Excavation Software, 2020) It can produce basic reports.

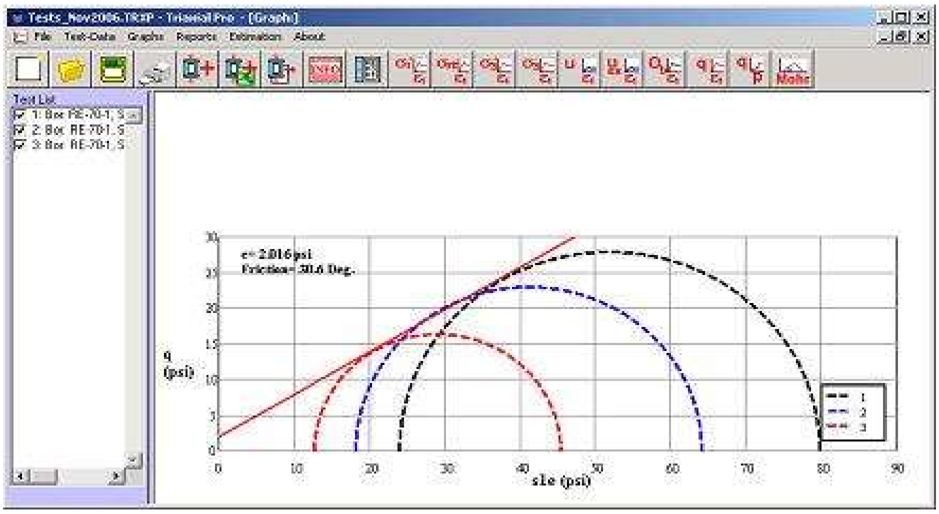
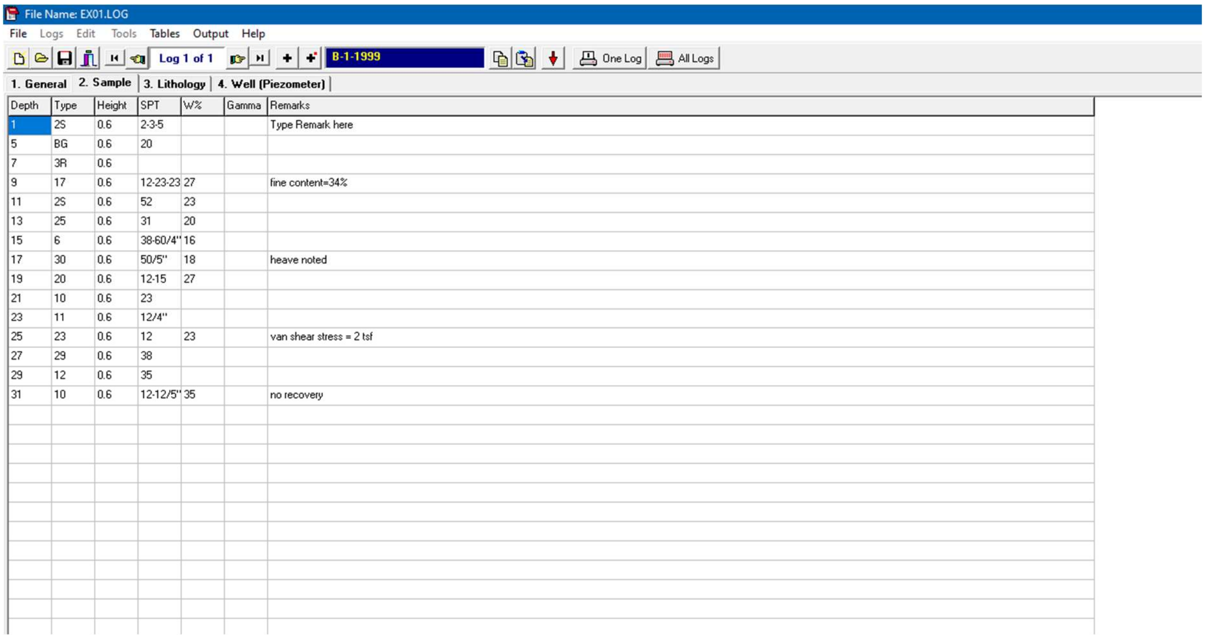


Figure 6 – Deep Excavation Software (Deep Excavation Software, 2020)

3.3.3 CivilTech Software

CivilTech Software was developed in the United States of America. CivilTech Software employs structural, geotechnical, construction, and software engineering engineers to develop series of engineering programs. SuperLog is the part of the software closest to an ISGE. For field drilling and geotechnical investigations, SuperLog generates boring logs and test pit graphical reports. In addition, the logs can be pasted into Microsoft Word so that boring logs can be used in a geotechnical report (CivilTech, 2008). The software is database compatible but does not have its own user-assessable database that can be used beyond the temporary database.



Depth	Type	Height	SPT	W%	Gamma	Remarks
1	2S	0.6	2-3-5			Type Remark here
5	BG	0.6	20			
7	3R	0.6				
9	17	0.6	12-23-23	27		fine content=34%
11	2S	0.6	52	23		
13	25	0.6	31	20		
15	6	0.6	38-60/4"	16		
17	30	0.6	50/5"	18		heave noted
19	20	0.6	12-15	27		
21	10	0.6	23			
23	11	0.6	12/4"			
25	23	0.6	12	23		van shear stress = 2 tsf
27	29	0.6	38			
29	12	0.6	35			
31	10	0.6	12-12/5"	35		no recovery

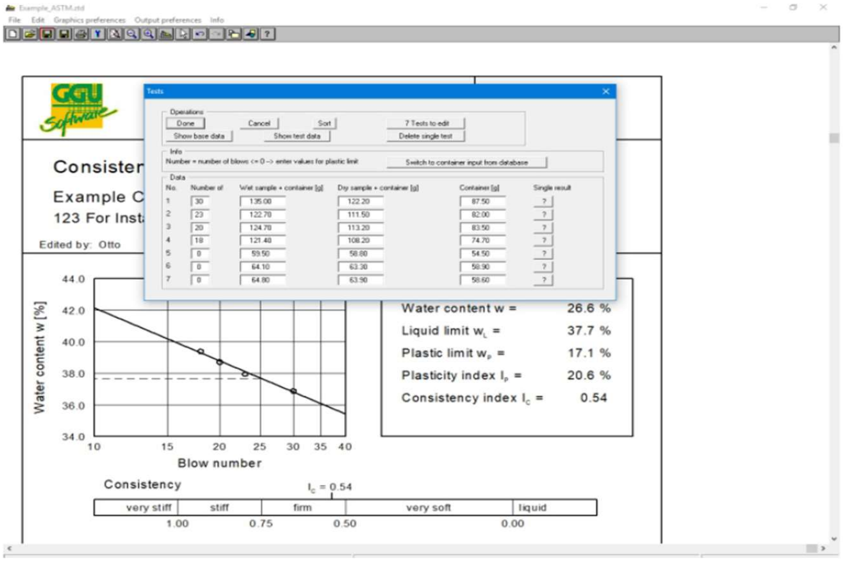
Figure 7 - CivilTech Software (CivilTech, 2008)

3.3.4 GGU Software

The GGU software range contains 50 programs for disciplines in geotechnical calculations, groundwater flow models, borehole evaluations, soil mechanical laboratory and field tests. The following programs in this range have some of the information system criteria required for the ISGE:

3.3.4.1 GGU-Atterberg

GGU-Atterberg is used to assess and visualise the plastic limit and liquid limit tests (Atterberg limits) according to Casagrande method and uses empirical equations or machine correction factors. It can also produce shrinkage limit presentations and produce tables of the results (Buß, GGU-ATTERBERG, 2019).



Number = number of blows <= 0 --> enter values for plastic limit

No.	Number of	Wet sample + container [g]	Dry sample + container [g]	Container [g]	Single result
1	30	135.00	122.20	87.50	?
2	23	122.70	111.50	82.00	?
3	20	124.70	113.20	83.50	?
4	18	121.40	108.20	74.70	?
5	0	59.50	58.80	54.50	?
6	0	64.10	63.30	58.90	?
7	0	64.80	63.90	58.60	?

Water content w = 26.6 %
Liquid limit w_L = 37.7 %
Plastic limit w_P = 17.1 %
Plasticity index I_P = 20.6 %
Consistency index I_C = 0.54

I_C = 0.54

Figure 8 – GGU ATTERBERG software (Buß, GGU-Atterberg, 2019)

3.2.5.2 Compact

It is used for the assessment and visualisation of proctor compaction tests (not the same compaction test as the required SANS3001-GR30). It can visualise the saturation curve and air space ratio. The corrected proctor curve for coarse-grained soils with oversize grain and oversize curve grain (Buß, GGU-COMPACT, 2019).

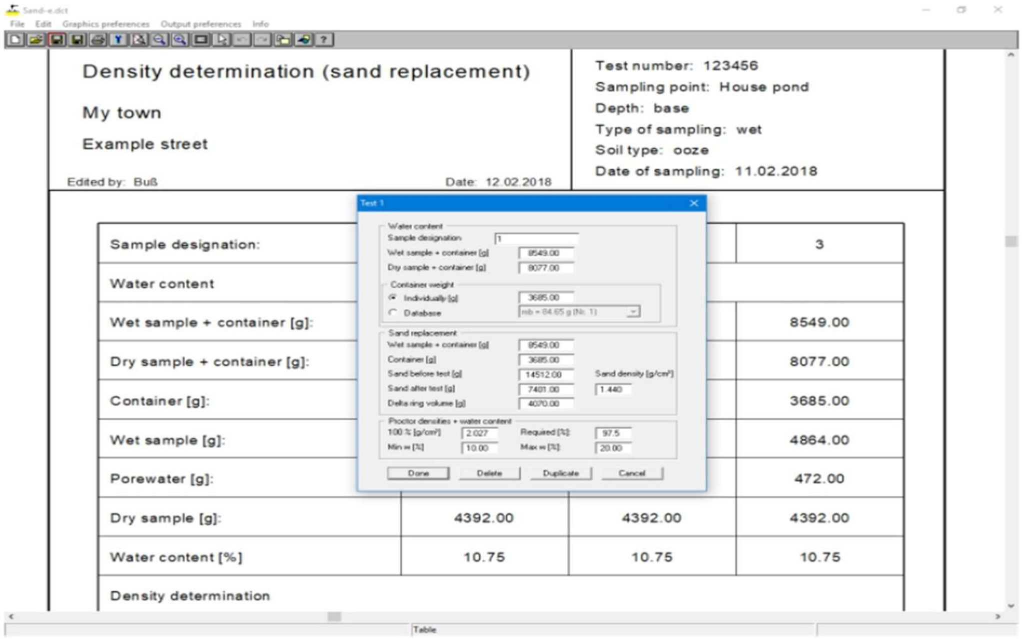
3.3.4.2 GGU-Density

GGU-Density determines and visualises the soil density. The program provides the following three different methods of density determination:

- The mould method

- Sand replacement method (Not required by ISGE)
- Densitometer method (Not required by ISGE)

It also determines the water content, density, wet density, dry density and compaction according to the selected method (Buß, GGU-DENSITY, 2019).



Density determination (sand replacement)

My town

Example street

Edited by: Buß

Date: 12.02.2018

Test number: 123456
Sampling point: House pond
Depth: base
Type of sampling: wet
Soil type: ooze
Date of sampling: 11.02.2018

Sample designation:			3
Water content			
Wet sample + container [g]:			8549.00
Dry sample + container [g]:			8077.00
Container [g]:			3685.00
Wet sample [g]:			4864.00
Porewater [g]:			472.00
Dry sample [g]:	4392.00	4392.00	4392.00
Water content [%]	10.75	10.75	10.75
Density determination			

Test 1

Water content
Sample designation: 1
Wet sample + container [g]: 8549.00
Dry sample + container [g]: 8077.00

Container weight
● Individually [g]: 3685.00
○ Database: mb = 84.65 g (Nr. 1)

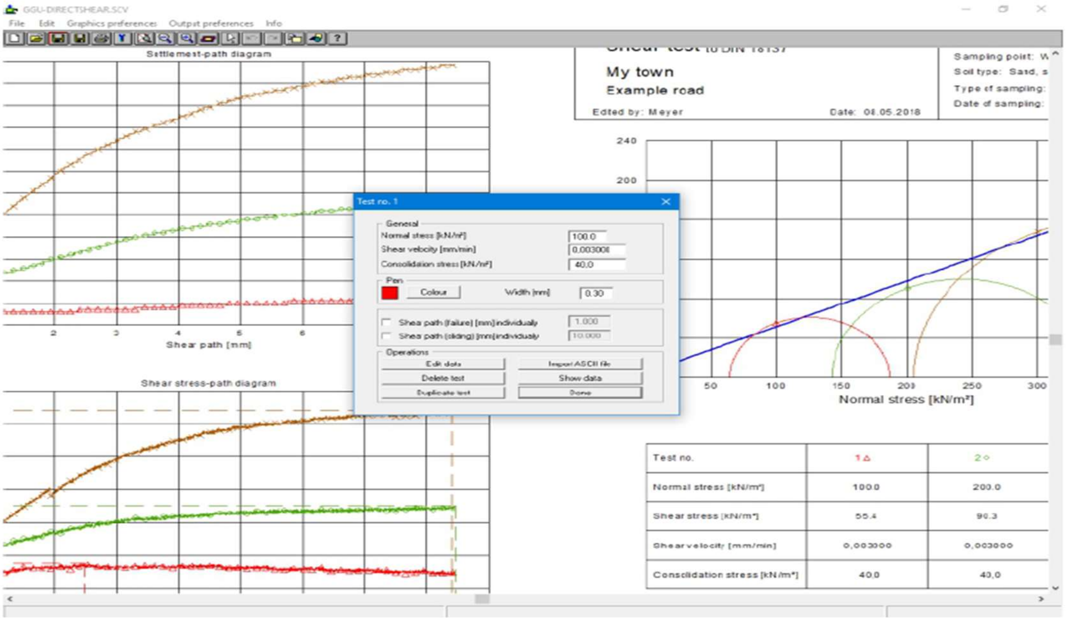
Sand replacement
Wet sample + container [g]: 8549.00
Container [g]: 3685.00
Sand before test [g]: 14512.00
Sand after test [g]: 7401.00
Delta ring volume [g]: 4070.00
Sand density [g/cm³]: 1.440

Proctor densities + water content
100 % [g/cm³]: 2.027
Required [%]: 97.5
Min w [%]: 10.00
Max w [%]: 20.00

Figure 9 - GGU-Density Program (Buß, GGU-Density, 2019).

3.3.4.3 GGU-DirectShear

This program evaluates and visualises test results of direct shear test procedures. The results are shown visually in the shear diagram for shear or triaxial tests and stress circles are shown graphically. The program also displays settlement-displacement and shear stress-displacement diagrams. All relevant test data is shown (Buß, GGU-DIRECTSHEAR, 2019).



My town
Example road
Edited by: Meyer
Date: 08.05.2018

Sampling point:
Soil type: Sand,
Type of sampling:
Date of sampling:

Test no. 1

General
Normal stress [kN/m²]: 100.0
Shear velocity [mm/min]: 0.003000
Consolidation stress [kN/m²]: 40.0

Pen
Width [mm]: 0.30

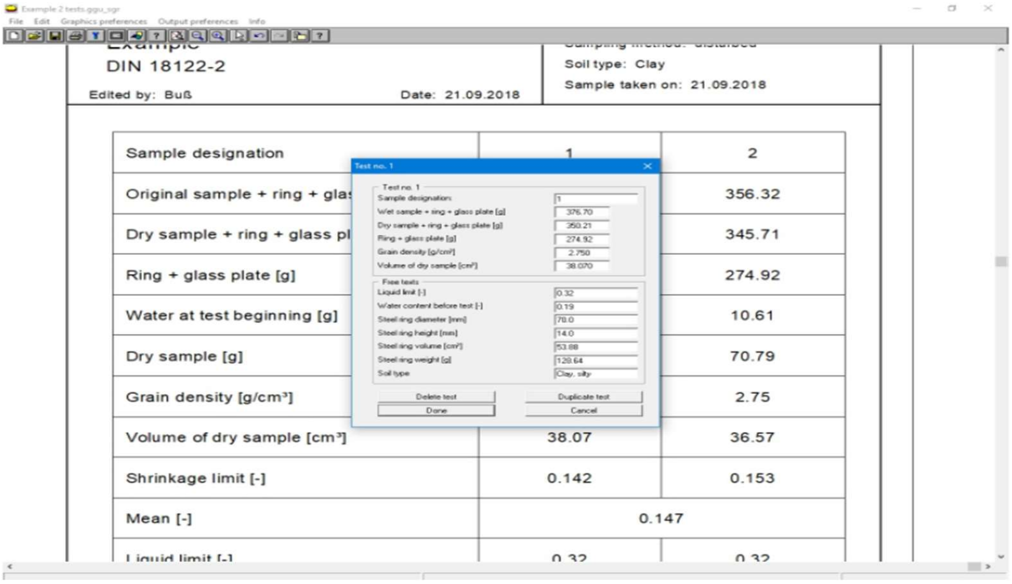
☐ Shear path (failure) [mm] individually: 1.000
☐ Shear path (sliding) [mm] individually: 10.000

Test no.	1 △	2 ○
Normal stress [kN/m²]	100.0	200.0
Shear stress [kN/m²]	55.4	90.3
Shear velocity [mm/min]	0,003000	0,003000
Consolidation stress [kN/m²]	40.0	40,0

Figure 10 – GGU-DirectShear Program (Buß, GGU-Directshear, 2019)

3.3.4.4 GGU-Shrinkage

Evaluation and visualisation of tests to determine shrinkage limit. The shrinkage limit itself, however, is not relevant for the ISGE
(Buß, GGU-SHRINKAGE, 2019).



DIN 18122-2
Edited by: Buß
Date: 21.09.2018

Soil type: Clay
Sample taken on: 21.09.2018

Sample designation	1	2
Original sample + ring + glas		356.32
Dry sample + ring + glass pl		345.71
Ring + glass plate [g]		274.92
Water at test beginning [g]		10.61
Dry sample [g]		70.79
Grain density [g/cm³]		2.75
Volume of dry sample [cm³]	38.07	36.57
Shrinkage limit [-]	0.142	0.153
Mean [-]	0.147	
Liquid limit [-]	0.32	0.32

Test no. 1

Test no. 1
Sample designation: 1
Wet sample + ring + glass plate [g]: 376.70
Dry sample + ring + glass plate [g]: 350.21
Ring + glass plate [g]: 274.92
Grain density [g/cm³]: 2.750
Volume of dry sample [cm³]: 38.070

Free texts
Liquid limit [-]: 0.32
Water content before test [-]: 0.19
Steel ring diameter [mm]: 70.0
Steel ring height [mm]: 14.0
Steel ring volume [cm³]: 53.88
Steel ring weight [g]: 128.64
Soil type: Clay, silty

Figure 11 - GGU-Shrinkage program

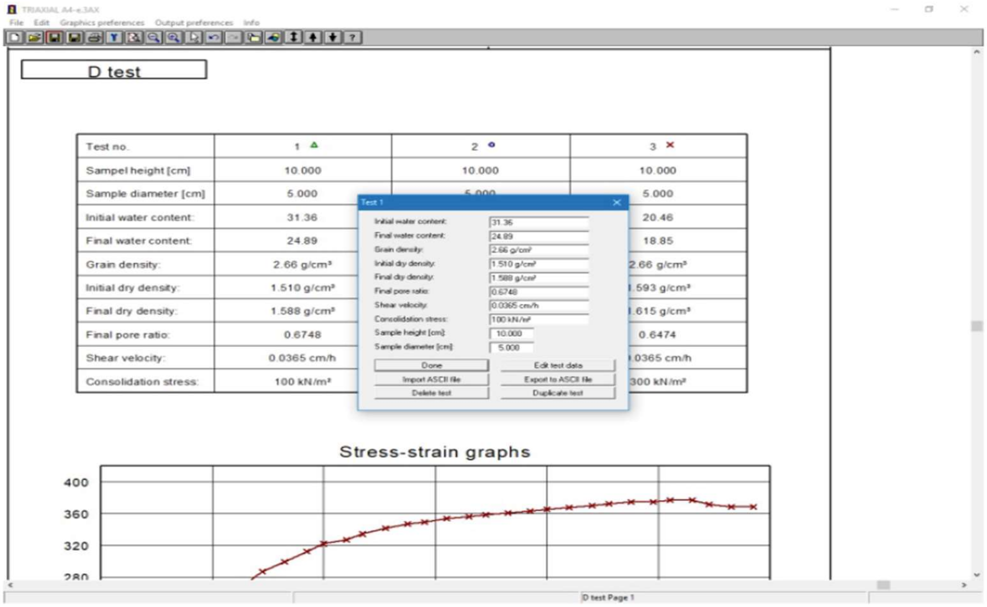
3.3.4.5 GGU-Sieve

GGU-SIEVE evaluates and presents particle size distribution using sieve analysis and hydrometer analyses. The software outputs test results as graphics of percentages of grain fractions and as laboratory logs. It computes the uniformity coefficients and coefficients of curvature, C_U and C_c as well as the grain sizes at d_{10}, d_{30}, d_{50}, d_{60}. The coefficients of the plasticity and the liquid limits are also considered for fine-grained soils. (Buß, GGU-Sieve, 2019)

3.3.4.6 GGU-Triaxial

The GGU-Triaxial software deals with triaxial compression. However, the consolidated undrained and unconsolidated undrained tests can be evaluated. The program can determine the following:

- Shear parameters,
- Different failure criteria,
- Stress circles,
- Stress ratio-strain graphs, Stress paths diagrams,
- Stress-strain graphs, and
- Volume-strain graphs (Buß, GGU-Triaxial, 2019).



Test no.	1 △	2 ○	3 ×
Sampel height [cm]	10.000	10.000	10.000
Sample diameter [cm]	5.000		5.000
Initial water content:	31.36		20.46
Final water content:	24.89		18.85
Grain density:	2.66 g/cm³		2.66 g/cm³
Initial dry density:	1.510 g/cm³		1.593 g/cm³
Final dry density:	1.588 g/cm³		1.615 g/cm³
Final pore ratio:	0.6748		0.6474
Shear velocity:	0.0365 cm/h		0.0365 cm/h
Consolidation stress:	100 kN/m²		300 kN/m²

Test 1

Initial water content: 31.36
Final water content: 24.89
Grain density: 2.66 g/cm³
Initial dry density: 1.510 g/cm³
Final dry density: 1.588 g/cm³
Final pore ratio: 0.6748
Shear velocity: 0.0365 cm/h
Consolidation stress: 100 kN/m²
Sample height [cm]: 10.000
Sample diameter [cm]: 5.000

Figure 12 - GGU-Triaxial Program (Buß, GGU-Triaxial, 2019)

3.3.5 DC Software

DC-Software in Munich, Germany, develops and distributes software for soil engineering.

3.3.5.1 DCPROC

Produces results for the proctor test (not the correct test for the ISGE), simple or modified proctor test (closer to SANS3001-GR30). It evaluates the proctor density and optimum water content (OMC) and determines the percent values for w_{min} and w_{max}. The software also graphically displays these measured values.

3.3.5.2 DC SECTION

DC SECTION displays the soil layers and has complete layer management of drill or borehole maps. However, it does not follow the same principles as SAICE (DC Software, 2020).

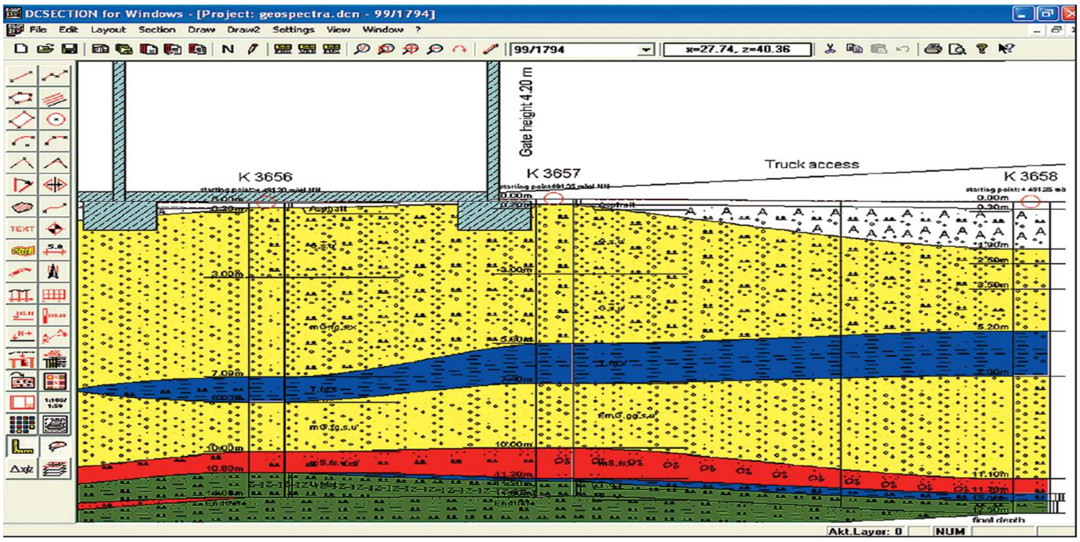
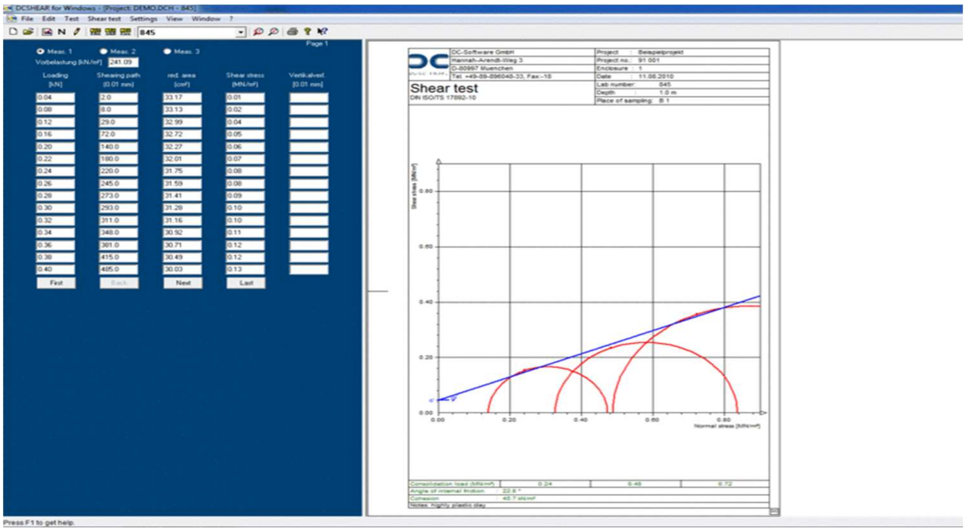


Figure 13 – DCSECTION Program (DC Software, 2020)

3.3.5.3 DCSHEAR

Direct shear test results can be assessed by DCSHEAR software where the various sample shapes can be assessed. Loading can be added in metric units used in South Africa). It can evaluate the friction angles and cohesion while graphically displaying the shear circles and the vertical deformation.



DC-Software GmbH
Hannah-Arendt-Weg 3
D-80997 Muenchen
Tel. +49-89-896048-33, Fax:-18

Shear test
DIN ISO/TS 17892-10

Project : Beispielprojekt
Project no.: 91 001
Enclosure : 1
Date : 11.08.2010
Lab number: 845
Depth : 1.0 m
Place of sampling: B 1

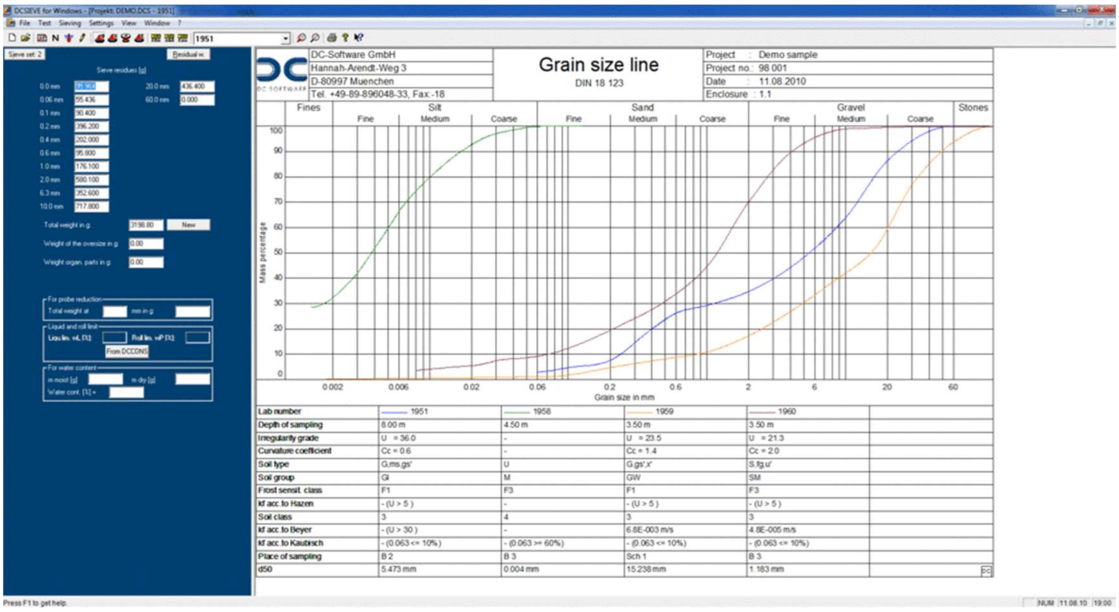
Consolidation load [MN/m²]	0.24	0.48	0.72

Angle of internal friction : 22.8 °
Cohesion : 45.7 kN/m²
Notes: highly plastic clay

Figure 14- DCSHEAR Program (DC Software, 2020)

3.3.5.4 DCSIEVE

DCSIEVE assesses sieve analysis test and can be used for any sieve sets. This could allow it to cater for a section of the SANS3001-GR1 but is limited by the other steps in the code. The sediment coefficients, detailed evaluations, curvature coefficient C_C, soil type, and grain sizes (d_{10} / d_{60}) can also be determined.



DC-Software GmbH
Hannah-Arendt-Weg 3
D-80997 Muenchen
Tel. +49-89-896048-33, Fax:-18

Grain size line
DIN 18 123

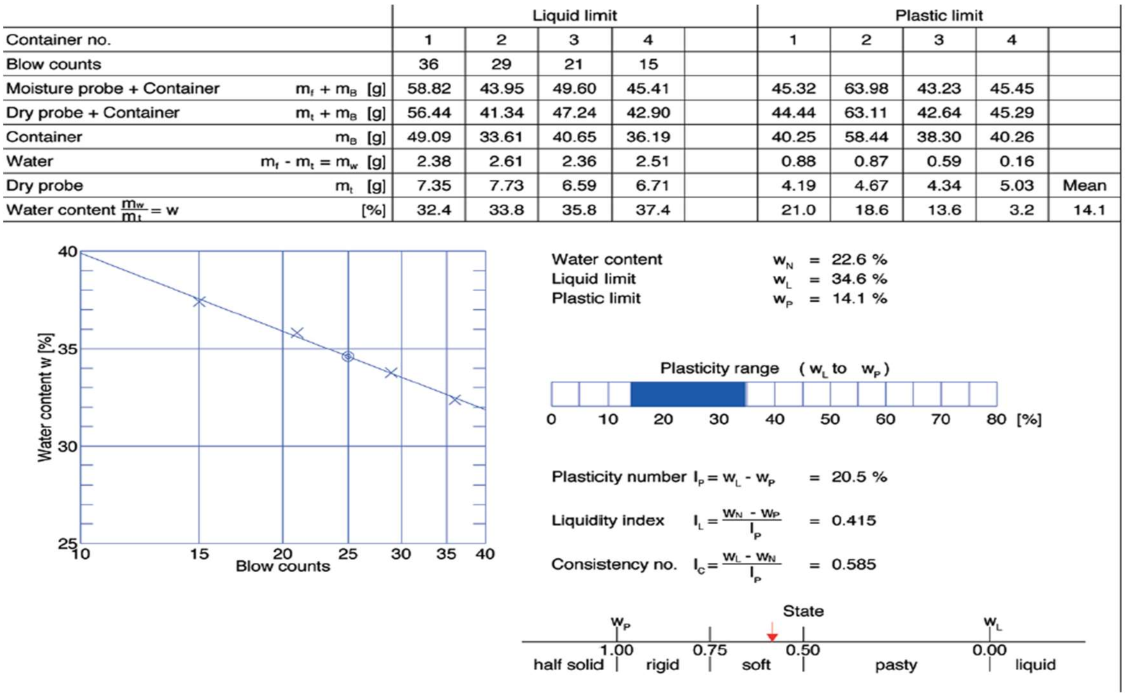
Project : Demo sample
Project no.: 98 001
Date : 11.08.2010
Enclosure : 1.1

Lab number	1951	1958	1959	1960	
Depth of sampling	8.00 m	4.50 m	3.50 m	3.50 m	
Irregularity grade	U = 36.0	-	U = 23.5	U = 21.3	
Curvature coefficient	Cc = 0.6	-	Cc = 1.4	Cc = 2.0	
Soil type	G,ms,gs'	U	G,gs',x'	S,fg,u'	
Soil group	GI	M	GW	SM	
Frost sensit. class	F1	F3	F1	F3	
kf acc. to Hazen	- (U > 5)	-	- (U > 5)	- (U > 5)	
Soil class	3	4	3	3	
kf acc. to Beyer	- (U > 30)	-	6.8E-003 m/s	4.8E-005 m/s	
kf acc. to Kaubisch	- (0.063 <= 10%)	- (0.063 >= 60%)	- (0.063 <= 10%)	- (0.063 <= 10%)	
Place of sampling	B 2	B 3	Sch 1	B 3	
d50	5.473 mm	0.004 mm	15.238 mm	1.183 mm	

Figure 15 – DCSIEVE (DC Software, 2020)

3.3.5.5 DCCONS

DCONS can be used for determination of liquid and plastic limits, plasticity range, plasticity index, or even make use of the one-point or three-point methods. It can also consider of the oversize grain and water content.



		Liquid limit					Plastic limit				
Container no.		1	2	3	4		1	2	3	4	
Blow counts		36	29	21	15						
Moisture probe + Container	$m_f + m_B$ [g]	58.82	43.95	49.60	45.41		45.32	63.98	43.23	45.45	
Dry probe + Container	$m_t + m_B$ [g]	56.44	41.34	47.24	42.90		44.44	63.11	42.64	45.29	
Container	m_B [g]	49.09	33.61	40.65	36.19		40.25	58.44	38.30	40.26	
Water	$m_f - m_t = m_w$ [g]	2.38	2.61	2.36	2.51		0.88	0.87	0.59	0.16	
Dry probe	m_t [g]	7.35	7.73	6.59	6.71		4.19	4.67	4.34	5.03	Mean
Water content $\frac{m_w}{m_t} = w$	[%]	32.4	33.8	35.8	37.4		21.0	18.6	13.6	3.2	14.1

Water content w_N = 22.6 %
Liquid limit w_L = 34.6 %
Plastic limit w_P = 14.1 %

Plasticity number $I_P = w_L - w_P$ = 20.5 %

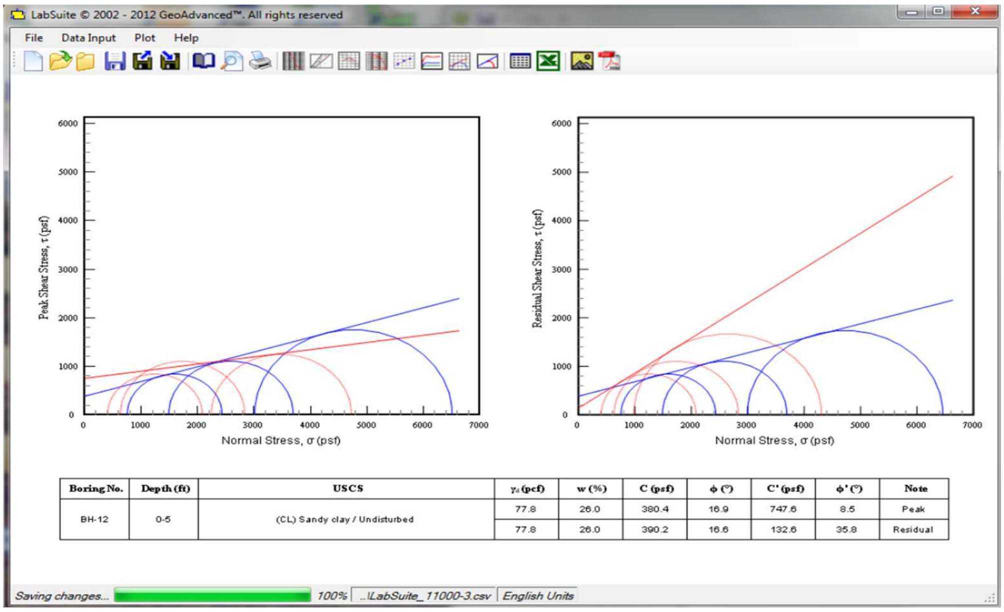
Liquidity index $I_L = \frac{w_N - w_P}{I_P}$ = 0.415

Consistency no. $I_C = \frac{w_L - w_N}{I_P}$ = 0.585

Figure 16 – DCCONS Program (DC Software, 2020)

3.3.6 GeoAdvanced

LabSuite is a geotechnical laboratory testing software package from GeoAdvanced that plots geotechnical laboratory testing results of soils. can assess tests that vary from particle size determination testing to triaxial shear testing. LabSuite automatically generates soil classifications based on the USCS and calculates parameters such as compression indexes and shear strength parameters. Reports can be generated and can be included in geotechnical reports. The program covers geotechnical test result data for grading curves, hydrometer, plasticity index, compaction, consolidation, direct shear, and triaxial shear tests.



Boring No.	Depth (ft)	USCS	γ_d (pcf)	w (%)	C (psf)	ϕ (°)	C' (psf)	ϕ' (°)	Note
BH-12	0-5	(CL) Sandy clay / Undisturbed	77.8	26.0	380.4	16.9	747.6	8.5	Peak
			77.8	26.0	390.2	16.6	132.6	35.8	Residual

Figure 17 - LabSuite Shear (GeoAdvanced, 2020)

3.3.7 GEOSYSTEM Software

GEOSYSTEM software is geotechnical software that produces boring logs plots, monitors well installation and produces test pit logs. It can calculate and report results from standard geotechnical tests through storing, reporting, and analysing the test results.

3.3.7.1 CLSUITE

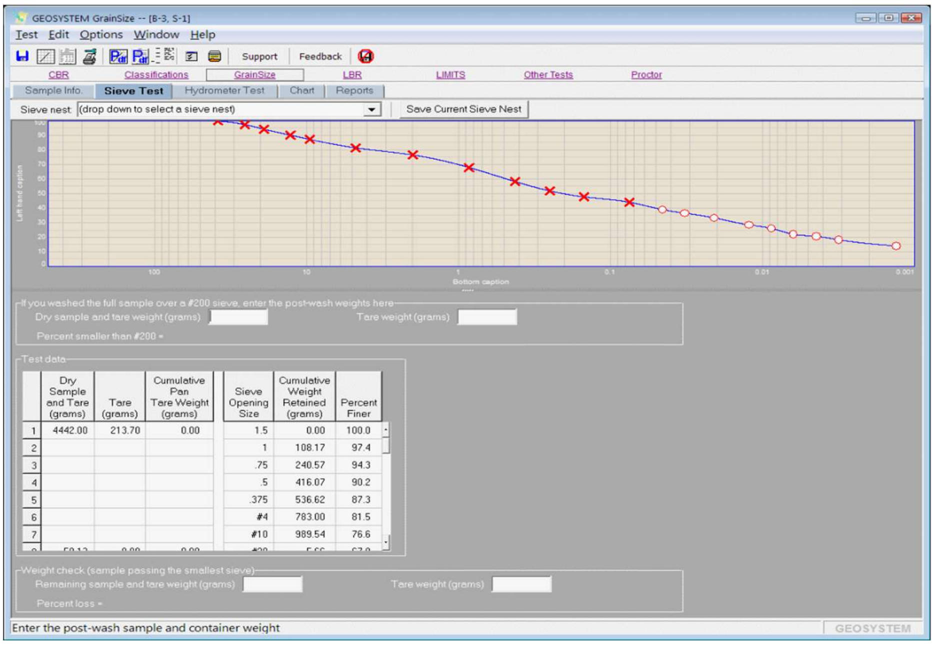
The GEOSYSTEM Classification Suite package (CLSuite) combines software for calculating grain size distribution curves, Atterberg limits (liquid, plastic limits, plasticity index) and automatically classifies soils using USCS, AASHTO, and other classification methods. CLSuite generates grain size, Atterberg limits and textural classification reports (not required from ISGE) from laboratory test data.

Grain size data may be entered as either raw testing data or as final calculated test results. This option allows the engineer to chart pre-calculated grain size tests without needing to access the original testing data.

Parameters such as the moduli, grain size diameters (D_{10}, D_{30} and D_{60}), coefficient of uniformity (C_u) and curvature (C_c), are calculated in the CLSuite software. Calculations for Atterberg limits include support for one-point liquid limit tests and calculation of plasticity and liquidity indices.

3.3.7.2 GEOSYSTEM GRAINSIZE

This program reduces the data from sieve and hydrometer tests. From the test data, the software calculates fineness modulus, percentage diameters (e.g., D_{10}, D_{30} and D_{60}), coefficient of uniformity (C_U) and curvature (C_C), and fractional components (e.g., the percentage of cobbles, gravel, sand, silt and clay in the material tested). Fractional components can be calculated based on the cobbles/gravel/sand/silt/clay particle sizes dictated by the user's choice of ASTM, AASHTO, Wentworth, Burmister or Australian (AS 1726) standards (but not the SANS3001 standards).



Sieve nest: (drop down to select a sieve nest)

If you washed the full sample over a #200 sieve, enter the post-wash weights here
Dry sample and tare weight (grams)
Tare weight (grams)
Percent smaller than #200 =

Test data

	Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
1	4442.00	213.70	0.00	1.5	0.00	100.0
2				1	108.17	97.4
3				.75	240.57	94.3
4				.5	416.07	90.2
5				.375	536.62	87.3
6				#4	783.00	81.5
7				#10	989.54	76.6

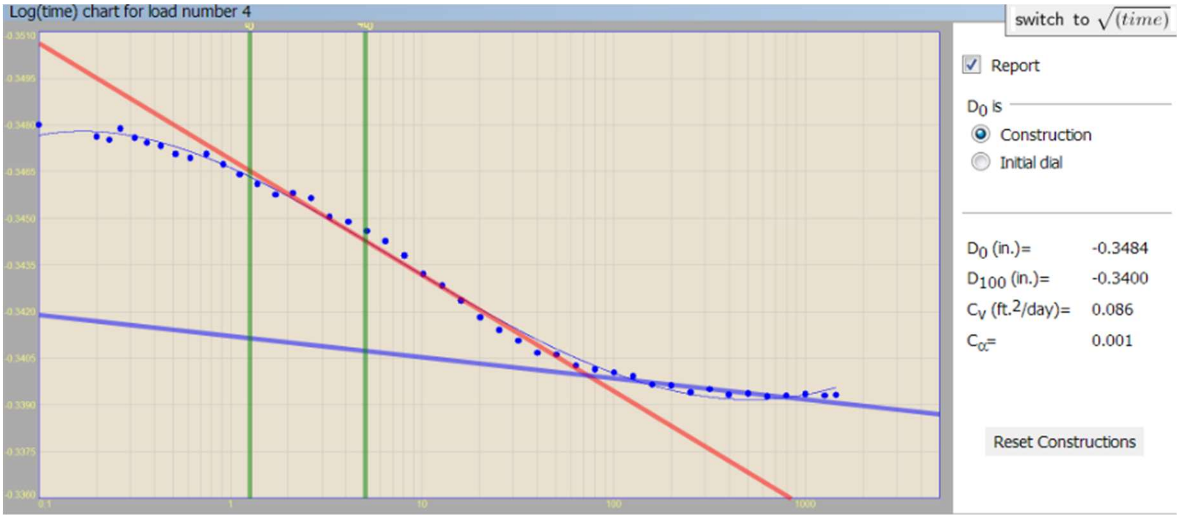
Weight check (sample passing the smallest sieve)
Remaining sample and tare weight (grams)
Tare weight (grams)
Percent loss =

Enter the post-wash sample and container weight

Figure 18 - GEOSYSTEM CLSuite graph and data input

3.3.7.3 GEOSYSTEM CONS

This program reports the data from one-dimensional consolidation or swell tests. The software features full reduction of time-consolidation data, including both square root and log of time methods. Coefficient of primary and secondary consolidation, void ratios, compression and recompression indices, consolidation and swell pressures, T_0, T_{50}, T_{90} and T_{100}, and swell/collapse percentages are calculated and reported. The test data can also be exported.



☑ Report

D_0 is

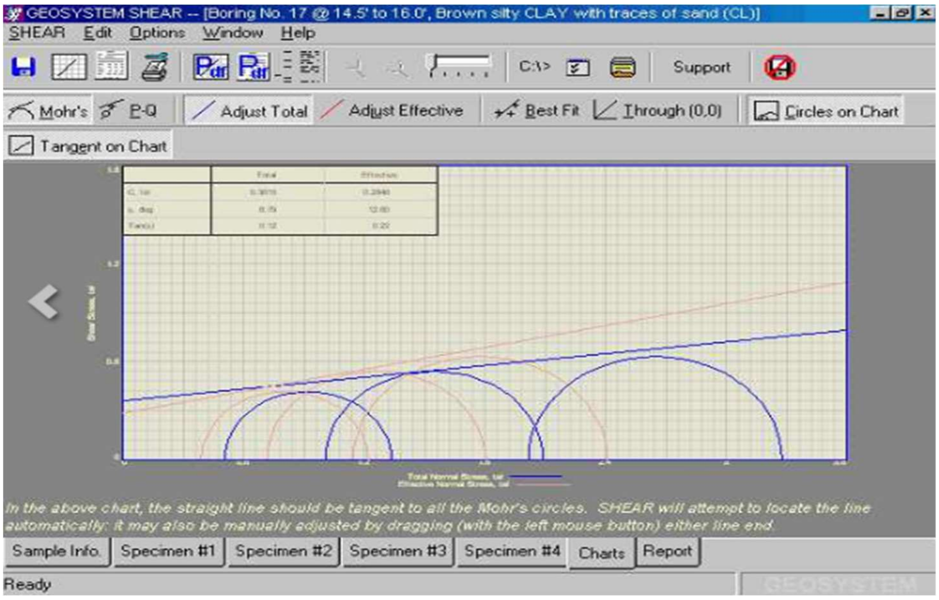
● Construction
○ Initial dial

D_0 (in.)= -0.3484
D_{100} (in.)= -0.3400
C_v (ft.^{2}/day)= 0.086
C_α= 0.001

Figure 19 - GEOSYSTEMS CONS

3.3.7.4 GEOSYSTEM SHEAR

This program reduces the data from triaxial shear, direct shear and unconfined compression tests. Support is included for triaxial pore pressure or drained test burette readings and vertical deformation readings during direct shear testing. SHEAR is compatible with both American Corps of Engineers and the American Society for Testing and Materials (ASTM) testing procedures and will also handle staged (single specimen, multiple shear runs at different normal or confining stresses) and geomembrane tests but does not support the SANS3001. The software calculates unconsolidated undrained (UU), consolidated undrained (CU), and consolidated drained (CU) triaxial tests.



GEOSYSTEM SHEAR -- [Boring No. 17 @ 14.5' to 16.0', Brown silty CLAY with traces of sand (CL)]

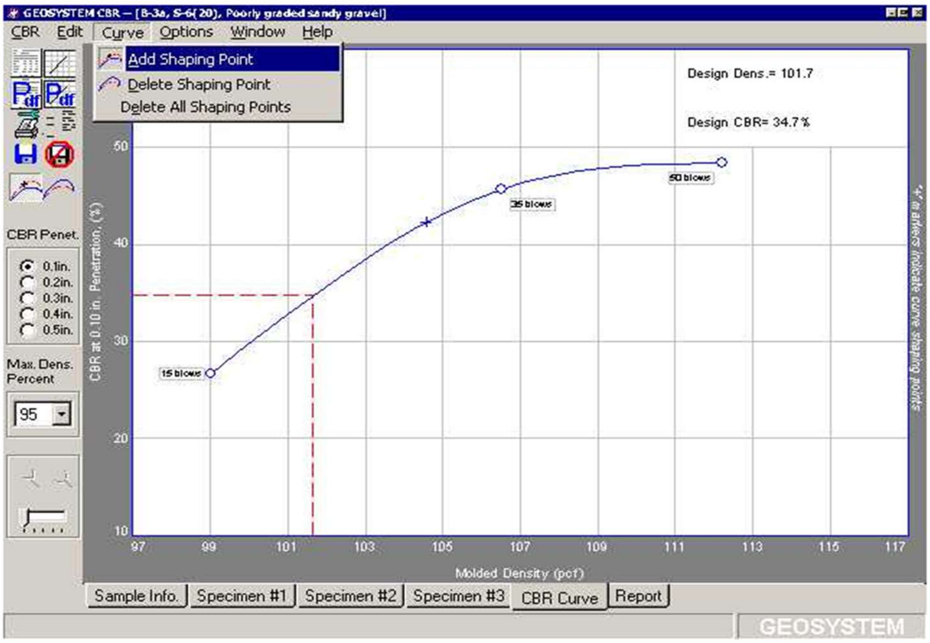
In the above chart, the straight line should be tangent to all the Mohr's circles. SHEAR will attempt to locate the line automatically: it may also be manually adjusted by dragging (with the left mouse button) either line end.

Ready

Figure 20 - GEOSYSTEMS Shear

3.3.7.5 GEOSYSTEM CBR

The GEOSYSTEM California Bearing Ratio Module is designed to reduce laboratory data from a California bearing ratio test. It utilises the GEOSYSTEM Data Manager program (GDM) for project information such as the project name and number are entered only once per project. The GDM can be used to create printed lists of all the CBR tests performed for a given project. The program interpolates data to determine the CBR at 95% maximum dry density.



GEOSYSTEM CBR – [B-3a, S-6(20), Poorly graded sandy gravel]

Design Dens.= 101.7

Design CBR= 34.7%

CBR Penet.
● 0.1in.
○ 0.2in.
○ 0.3in.
○ 0.4in.
○ 0.5in.

Max. Dens. Percent: 95

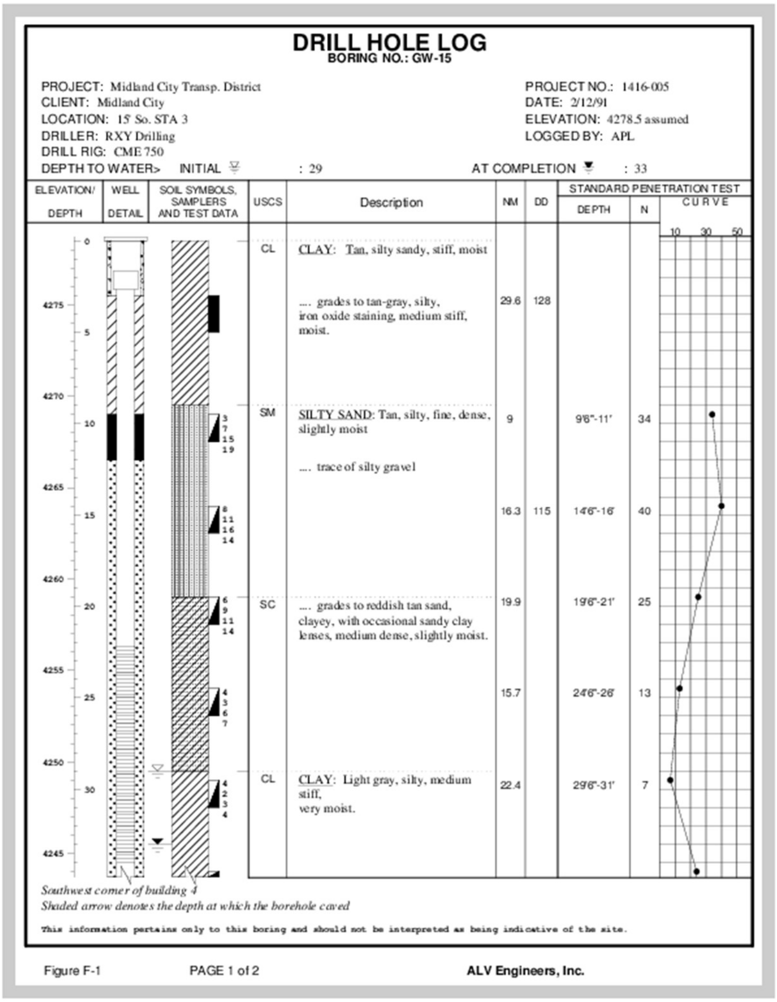
Figure 21 - GEOSYSTEM CBR graphing

3.3.7.6 GEOSYSTEM® PROCTOR

Proctor reduces and reports data from moisture-density (compaction) tests. Optimum moisture and maximum dry density results are automatically calculated from the moisture versus density curve and the results can be automatically corrected for the presence of oversize material.

3.3.7.7 GEOSYSTEM® LOGDRAFT Version

LOGDRAFT can be used as a standalone boring log program or in concert with one or more of the geosystem laboratory testing modules. The software is designed to meet the needs of geotechnical, geological and environmental professionals.



DRILL HOLE LOG
BORING NO.: GW-15

PROJECT: Midland City Transp. District
CLIENT: Midland City
LOCATION: 15' So. STA 3
DRILLER: RXY Drilling
DRILL RIG: CME 750
DEPTH TO WATER> INITIAL ▽ : 29

PROJECT NO.: 1416-005
DATE: 2/12/91
ELEVATION: 4278.5 assumed
LOGGED BY: APL
AT COMPLETION ▼ : 33

USCS	Description	NM	DD	STANDARD PENETRATION TEST DEPTH	N
CL	CLAY: Tan, silty sandy, stiff, moist				
	.... grades to tan-gray, silty, iron oxide staining, medium stiff, moist.	29.6	128		
SM	SILTY SAND: Tan, silty, fine, dense, slightly moist	9		9'6"-11'	34
	.... trace of silty gravel				
		16.3	115	14'6"-16'	40
SC	.... grades to reddish tan sand, clayey, with occasional sandy clay lenses, medium dense, slightly moist.	19.9		19'6"-21'	25
		15.7		24'6"-26'	13
CL	CLAY: Light gray, silty, medium stiff, very moist.	22.4		29'6"-31'	7

Southwest corner of building 4
Shaded arrow denotes the depth at which the borehole caved

This information pertains only to this boring and should not be interpreted as being indicative of the site.

Figure F-1 PAGE 1 of 2 **ALV Engineers, Inc.**

Figure 22 - LogDraft sample report

3.3.8 Gaea Software

Gaea Software is a Microsoft Windows-compatible program for mapping, data management, and evaluation of soil and rock properties. All the test data is stored in either the project and GIS databases or the database. The program is comprised of a base application and several extension modules. The base application of GaeaSynergy is used as a platform upon which all the other modules build.

The base application consists of the following components:

- Database management
- Exportation of files
- One of the primary data sources in the application comes from wells and borings.

The geotechnical data management system (GDMS) is used to schedule, report, and store a wide variety of geotechnical tests and data.

GaeaSynergy uses basemaps to organise, find, and select projects. Additionally, base maps are used as the basis for the GIS in GaeaSynergy. The GIS stores all the basemap, project, boring/well, station, sample, cross-section, and other spatial data for the application.

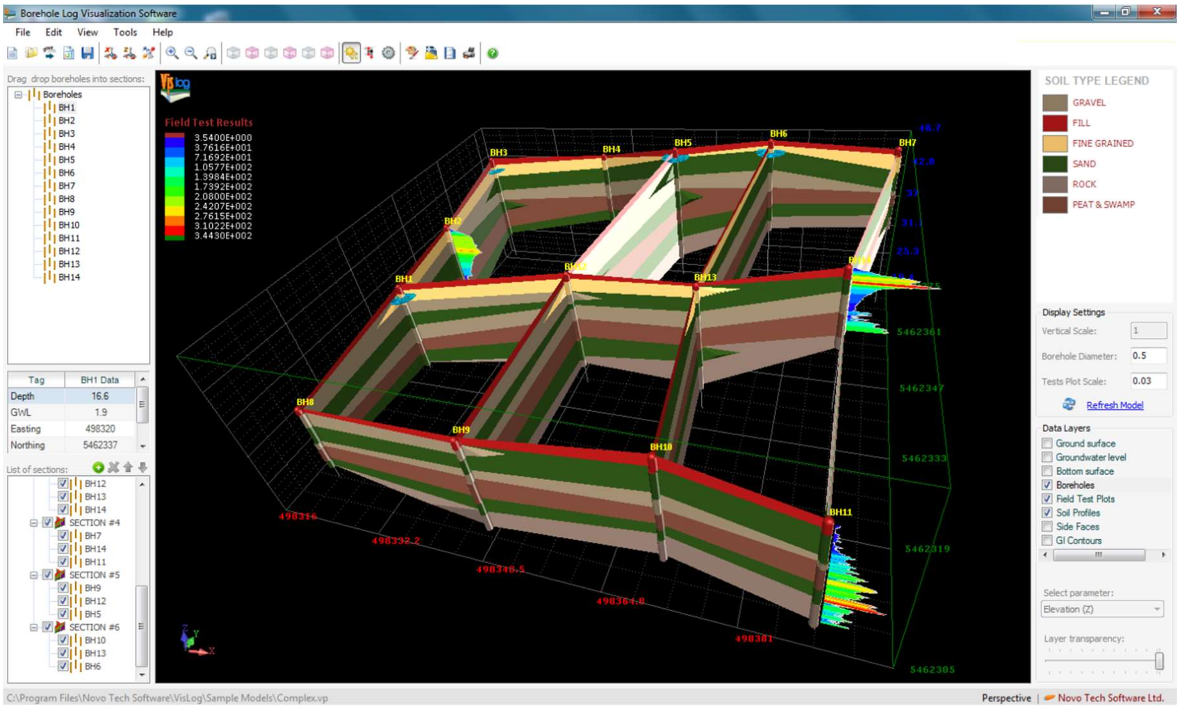
In GaeaSynergy, basemaps represent the geographic information as a collection of layers. These layers represent different datasets that are overlaid on the base map.

The GDMS integrates geotechnical testing and quality control with a laboratory information management system. The GDMS is also used to perform various geotechnical tests and store the data and results in a managed database.

3.3.9 NovoTech

3.3.9.1 VisLog

By using VisLog, an engineer will be able to enter borehole information, including depth, coordinates, and groundwater level, and have a three-dimensional interactive view of the subsurface soil layers of the site. VisLog helps users with making a 3D model of the soil layers close to real site conditions. Input data can be manually entered or imported from gINT or NovoLAB. Users can enter data using the borehole editor page.



Tag	BH1 Data
Depth	16.6
GWL	1.9
Easting	498320
Northing	5462337

Vertical Scale: 1
Borehole Diameter: 0.5
Tests Plot Scale: 0.03

☐ Ground surface
☐ Groundwater level
☐ Bottom surface
☑ Boreholes
☑ Field Test Plots
☑ Soil Profiles
☐ Side Faces
☐ GI Contours

Select parameter: Elevation (Z)

C:\Program Files\Novo Tech Software\VisLog\Sample Models\Complex.vp

Figure 23 – VisLog interface

3.3.10 gINT

Bentley's gINT software provides centralised data management and reporting for geotechnical subsurface projects of all types. The software automates many repetitive tasks, eliminates redundant data entry, and dramatically increases productivity. gINT allows users to streamline processes, provides accessible, interoperable data, and enhances subsurface reporting and visualisation for soil and rock, borelogs, lab tests, and more while increasing productivity and supporting better decision-making.

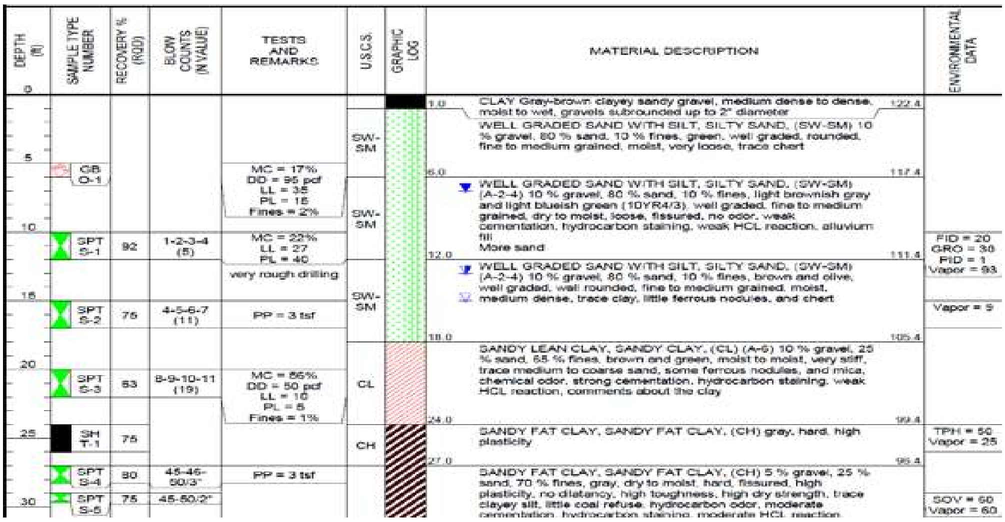
3.3.10.1 Data Interchange for Geotechnical and Geoenvironmental Specialists (DIGGS)

The software that is probably closest to the requirements of the ISGE is the DIGGS system. The DIGGS system involves development of a GML (XML-based) geospatial standard schema (GIS related systems) for the transfer of geotechnical and geoenvironmental data across the United States of America. DIGGS can work with existing software, hardware, databases and data storage facilities to easily transfer and share your data.

The DIGGS data transfer standards assist with the needs for information and data asset management among experts. DIGGS is expected to save American agencies, and businesses many costs including savings by avoiding unnecessary drilling and laboratory testing by availing geotechnical data from multiple projects in a standard format.

3.3.10.1 Visualise subsurface data in ArcGIS 3.3.10.1

gINT allows users to view subsurface data directly from ArcGIS, providing easy access to logs, lab data, reports, and more. The gINT for ArcGIS extension allows users to add the dimension of subsurface data to ArcGIS. Users can then generate gINT reports and query subsurface data directly from ArcMap.



DEPTH (ft)	SAMPLE TYPE NUMBER	RECOVERY % (RQD)	BLOW COUNTS (N VALUE)	TESTS AND REMARKS	U.S.C.S.	GRAPHIC LOG	MATERIAL DESCRIPTION	ENVIRONMENTAL DATA
0							CLAY Gray-brown clayey sandy gravel, medium dense to dense, moist to wet, gravels subrounded up to 2" diameter 1.0 122.4	
5					SW-SM		WELL GRADED SAND WITH SILT, SILTY SAND, (SW-SM) 10 % gravel, 80 % sand, 10 % fines, green, well graded, rounded, fine to medium grained, moist, very loose, trace chert 6.0 117.4	
	GB O-1			MC = 17% DD = 95 pcf LL = 35 PL = 15 Fines = 2%	SW-SM		WELL GRADED SAND WITH SILT, SILTY SAND, (SW-SM) (A-2-4) 10 % gravel, 80 % sand, 10 % fines, light brownish gray and light bluish green (10YR4/3), well graded, fine to medium grained, dry to moist, loose, fissured, no odor, weak cementation, hydrocarbon staining, weak HCL reaction, alluvium fill More sand 12.0 111.4	
10	SPT S-1	92	1-2-3-4 (5)	MC = 22% LL = 27 PL = 40 very rough drilling				FID = 20 GRO = 30 PID = 1 Vapor = 93
15	SPT S-2	75	4-5-6-7 (11)	PP = 3 tsf	SW-SM		WELL GRADED SAND WITH SILT, SILTY SAND, (SW-SM) (A-2-4) 10 % gravel, 80 % sand, 10 % fines, brown and olive, well graded, well rounded, fine to medium grained, moist, medium dense, trace clay, little ferrous nodules, and chert 18.0 105.4	Vapor = 5
20	SPT S-3	53	8-9-10-11 (19)	MC = 86% DD = 50 pcf LL = 10 PL = 5 Fines = 1%	CL		SANDY LEAN CLAY, SANDY CLAY, (CL) (A-6) 10 % gravel, 25 % sand, 65 % fines, brown and green, moist to moist, very stiff, trace medium to coarse sand, some ferrous nodules, and mica, chemical odor, strong cementation, hydrocarbon staining, weak HCL reaction, comments about the clay 24.0 99.4	
25	SH T-1	75			CH		SANDY FAT CLAY, SANDY FAT CLAY, (CH) gray, hard, high plasticity 27.0 96.4	TPH = 50 Vapor = 25
	SPT S-4	80	45-46-50/3"	PP = 3 tsf			SANDY FAT CLAY, SANDY FAT CLAY, (CH) 5 % gravel, 25 % sand, 70 % fines, gray, dry to moist, hard, fissured, high plasticity, no dilatancy, high toughness, high dry strength, trace clayey silt, little coal refuse, hydrocarbon odor, moderate cementation, hydrocarbon staining, moderate HCL reaction	
30	SPT S-5	75	45-50/2"					SOV = 60 Vapor = 60

Figure 24 - Subsurface data of gINT

With gINT Professional and gINT Professional Plus, users can quickly integrate lab testing results with other subsurface data. From raw lab data, gINT can perform calculations for any of thirteen different lab tests provided with the gINT installation. Once raw lab data has been entered into gINT, the resulting calculations can be used on any type of report: logs, fences, tables, and more.

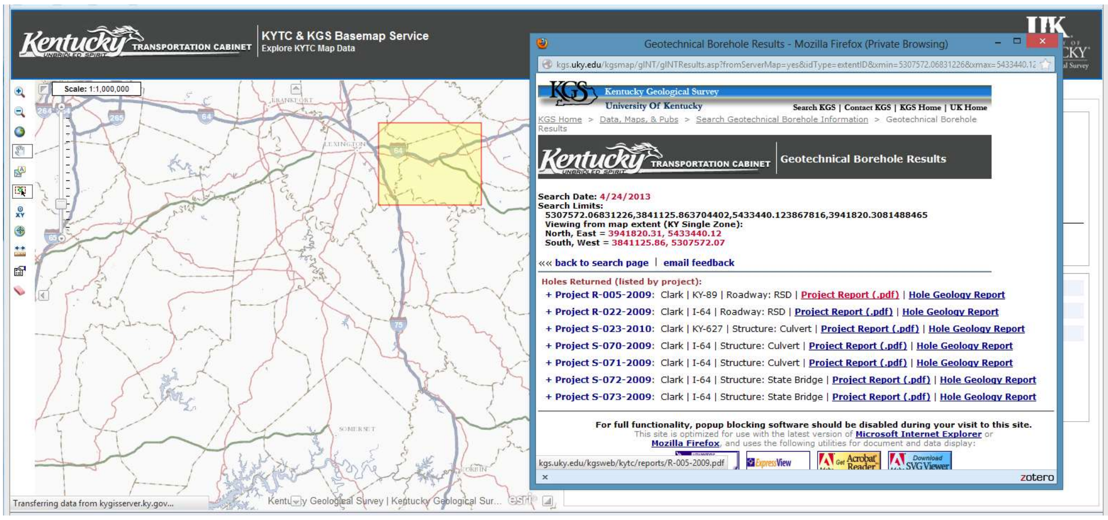
3.3.11 SVSoils

This suite has impressive capabilities in the 2D and 3D analysis of geostructures. The SVSoils system is a knowledge-based database system for saturated and unsaturated soils. It uses an advanced environment to perform assessments of saturated and unsaturated constitutive models to describe the behaviours of soil. The soil database contains data on over 2500 saturated permeability soils and unsaturated permeability data on over 700 soil samples across the USA. It allows the importing of project data into the database and allows the user to search the database and use estimations.

The experimental data for the particle size distribution curve is fitted using two equations to determine the percentage clay, silt, sand, and coarse materials and then classify it according to the AASHTO, the United States Department of Agriculture (USDA) and USCS classifications.

3.3.12 Kentucky Transportation Basemap Service

Using the geotechnical database is primarily intended to manage existing paper reports. Paper documents may first be digitised to the format of an image (such as a tagged image file format (TIFF) or portal document format (PDF). Kentucky Department of Transport (DOT), for example, developed a web-based database to manage the historic geotechnical PDF reports. The database was linked to a GIS server so that users can easily obtain all existing geotechnical reports on a map in each area.



Search Date: 4/24/2013
Search Limits:
5307572.06831226,3841125.863704402,5433440.123867816,3941820.3081488465
Viewing from map extent (KY Single Zone):
North, East = 3941820.31, 5433440.12
South, West = 3841125.86, 5307572.07

Holes Returned (listed by project):

- + Project R-005-2009: Clark | KY-89 | Roadway: RSD | Project Report (.pdf) | Hole Geology Report
- + Project R-022-2009: Clark | I-64 | Roadway: RSD | Project Report (.pdf) | Hole Geology Report
- + Project S-023-2010: Clark | KY-627 | Structure: Culvert | Project Report (.pdf) | Hole Geology Report
- + Project S-070-2009: Clark | I-64 | Structure: Culvert | Project Report (.pdf) | Hole Geology Report
- + Project S-071-2009: Clark | I-64 | Structure: Culvert | Project Report (.pdf) | Hole Geology Report
- + Project S-072-2009: Clark | I-64 | Structure: State Bridge | Project Report (.pdf) | Hole Geology Report
- + Project S-073-2009: Clark | I-64 | Structure: State Bridge | Project Report (.pdf) | Hole Geology Report

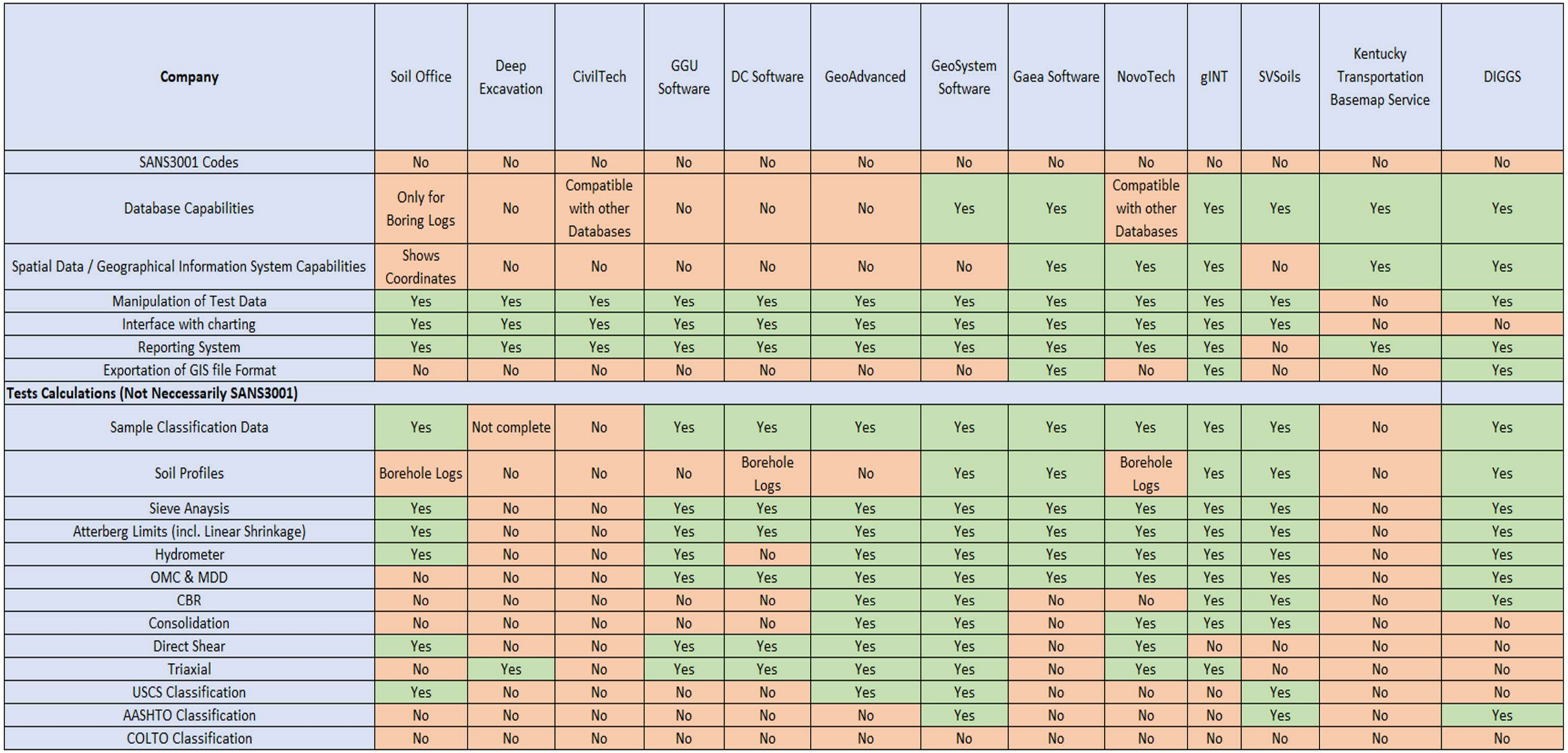
For full functionality, popup blocking software should be disabled during your visit to this site.
This site is optimized for use with the latest version of Microsoft Internet Explorer or Mozilla Firefox, and uses the following utilities for document and data display:

Figure 25 - Kentucky Transportation Basemap Service

More information can be catalogued, typically through manual input (e.g., report date, file creator, control section, and log mile), but that process was very labour-intensive. Although semi-automatic indexing is possible via special text recognition programs, quality control still requires a manual review of the indexed files. A better solution was to link the geotechnical database automatically to other existing DOT databases and extract more information about the project. Project information such as project number, date, longitude and latitude, contractor, and project manager can be found in the Louisiana Department of Transportation and Development (DOTD) Project Tracking (TOPS) database, for example (Yang, 2014).

3.4 Comparison of Available Software

Figure 26 below summarises the software by criteria used to create the ISGE in a table. The software study shows that most of the available software programs do not have all the requirements needed for an ISGE. However, the information system created during this thesis does have these requirements.



Company	Soil Office	Deep Excavation	CivilTech	GGU Software	DC Software	GeoAdvanced	GeoSystem Software	Gaea Software	NovoTech	gINT	SVSoils	Kentucky Transportation Basemap Service	DIGGS
SANS3001 Codes	No	No	No	No	No	No	No	No	No	No	No	No	No
Database Capabilities	Only for Boring Logs	No	Compatible with other Databases	No	No	No	Yes	Yes	Compatible with other Databases	Yes	Yes	Yes	Yes
Spatial Data / Geographical Information System Capabilities	Shows Coordinates	No	No	No	No	No	No	Yes	Yes	Yes	No	Yes	Yes
Manipulation of Test Data	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Interface with charting	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Reporting System	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Exportation of GIS file Format	No	No	No	No	No	No	No	Yes	No	Yes	No	No	Yes
Tests Calculations (Not Neccessarily SANS3001)													
Sample Classification Data	Yes	Not complete	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Soil Profiles	Borehole Logs	No	No	No	Borehole Logs	No	Yes	Yes	Borehole Logs	Yes	Yes	No	Yes
Sieve Anaysis	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Atterberg Limits (incl. Linear Shrinkage)	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Hydrometer	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
OMC & MDD	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
CBR	No	No	No	No	No	Yes	Yes	No	No	Yes	Yes	No	Yes
Consolidation	No	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No
Direct Shear	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	No
Triaxial	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	No
USCS Classification	Yes	No	No	No	No	Yes	Yes	No	No	No	Yes	No	No
AASHTO Classification	No	No	No	No	No	No	Yes	No	No	No	Yes	No	Yes
COLTO Classification	No	No	No	No	No	No	No	No	No	No	No	No	No

Figure 26 - Available software comparison

Most of the available software programs or packages had some criteria for an ISGE, but none of them completely fitted for an ISGE.

Except for the Kentucky Transportation Basemap Service, every program could transform test data into information. This information could also be displayed in an interface with charts and a form of report generation (in PDF or as a Microsoft document).

An essential requirement for an ISGE in South Africa is implementing the SANS3001 in the test methods and calculations. The comparison showed that none of the available software allows the use of the SANS3001 in their calculations. The COLTO classification was also not available in any of the programs. Most of the programs used codes specific to their country of origin or standard codes used by several countries, namely ASTM or Eurocodes.

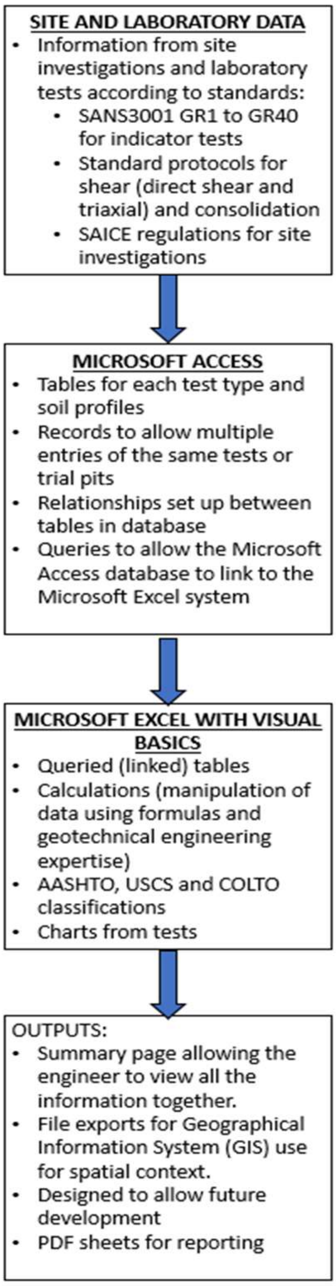
GEOSYSTEM, Gaea Software, gINT, Kentucky Transportation Basemap Service and SVSoils are all capable of storing their specific tests (in their codes/standards) in the program's database. Therefore, they have fully capable databases. However, these databases are limited to specific tests or codes and do not allow the entry of SANS3001 test data. In addition, some software is only compatible with other databases such as CivilTech and Novotech (which usually works with gINT).

Only Gaea and gINT software can export file formats for the use of GIS. The other available programs can only interact with a base map or directly with the GIS system within their system.

Considering all the information acquired during the study in Chapters 2 and 3, the ISGE can now be designed and created to fit all the requirements for making decisions during desktop studies in South Africa.

CHAPTER 4: PROCEDURE FOR CREATING THE ISGE

This chapter outlines the procedure that was adopted for the research project. It describes the method taken to develop the new ISGE. The basic outline of the information system for geotechnical engineers is shown in Figure 27:



SITE AND LABORATORY DATA
- Information from site investigations and laboratory tests according to standards:
  - SANS3001 GR1 to GR40 for indicator tests
  - Standard protocols for shear (direct shear and triaxial) and consolidation
  - SAICE regulations for site investigations

MICROSOFT ACCESS
- Tables for each test type and soil profiles
- Records to allow multiple entries of the same tests or trial pits
- Relationships set up between tables in database
- Queries to allow the Microsoft Access database to link to the Microsoft Excel system

MICROSOFT EXCEL WITH VISUAL BASICS
- Queried (linked) tables
- Calculations (manipulation of data using formulas and geotechnical engineering expertise)
- AASHTO, USCS and COLTO classifications
- Charts from tests

OUTPUTS:
- Summary page allowing the engineer to view all the information together.
- File exports for Geographical Information System (GIS) use for spatial context.
- Designed to allow future development
- PDF sheets for reporting

Figure 27 – Basic outline of ISGE

Based on the research done in Chapters 2 and 3, an initial design of the ISGE was proposed. The focus of the system was it being easily accessible when making key decisions for a geotechnical site investigation during the desktop study phase. Several sites' test data and information were collected, or tests were performed in the laboratory to collect sufficient data to identify the requirements of the database. The database was then designed and created to allow the storage of the collected data and future data. The information system was then designed to interpret the data or information to produce reliable information for decision-making. The system was assessed by the applicability of the outputs, and the database was updated to better suit the design.

In Chapter 3, the need for an ISGE in South Africa was examined, and a comparison was made to software available from other countries that have already developed similar systems. The use of information systems and databases were assessed to determine the demand for an ISGE in South Africa and to study concepts that work and identify those that do not work.

4.1 Determining the Need for an ISGE in South Africa

The ISGE firstly needed to be defined before its development could be initiated. A list of criteria was determined to specify what the final program should comprise. These criteria included all the geotechnical engineering requirements and properties that would further define the system.

The geotechnical engineering requirements of the ISGE (tests, standards, codes of practice and classifications) were further studied. In Chapter 2, the importance of geotechnical investigations was discussed. The crucial information required for geotechnical reports was highlighted in terms of the requirements of the proposed database. Key design parameters and requirements were obtained by studying specific standards that require the information. The important lab tests used in geotechnical reports were also listed and studied to determine what is required by the ISGE.

The ISGE needed to consist of the Information System for manipulation and summarizing information and the database which stores and manages the data. The type of data that needs to be stored in the database should be actual data received from real tests and sites. To properly design the database and the rest of the ISGE, real data should be gathered and used to develop the system and later be stored.

4.1 Collecting Data for Design

A research group at the Central University of Technology, the Soil Mechanics Research Group, is actively involved in geotechnical engineering and soil mechanics research. The group often participates in geotechnical investigations where the soil is tested, results analysed and compared with associated commercial labs for duplicate testing purposes. The results are often stored on paper or individual Microsoft Excel sheets. This information is occasionally lost or forgotten. This was a primary reason for the development of the ISGE, especially the database component. This data was also used to test the software.

Large amounts of data are generated during site assessment projects. Geotechnical data collection, evaluation, and documentation can quickly become an issue in projects which may lead to them failing. When technical data is collected from various projects by different staff members under varying (or non-existent) documentation standards, it becomes even more difficult to decipher these records. (Sara, 2003)

These records of data can be divided into "generations" of information. Beginning with the first generation "raw" data with quality assurance/quality control (QA/QC). Planning documentation, raw field data, unedited logs, and tabular analytical data are all included in this first generation. Data from the first generation is usually very specific to the project. Interpretative drawings, cross-sections, and maps derived from raw data are examples of second-generation data. Statistical data evaluations and geographic information systems that overlay datasets to aid in interpretation are examples of third-generation data. Fourth-generation data allow for the prediction of future events by modeling the coming environmental conditions using lower-order generational data. (Sara, 2003) This project, however, will only focus on the first three generations of data while part of the third generation and the fourth generation will be done in future studies.

Software applications facilitate engineers’ tasks by improving the speed and precision of the design process. In addition, they save time, and reduce the total cost, workload, and required workforce compared to the same work performed manually. The choice of software depends on four criteria: specific project at hand, the extent and accessibility collected data (inputs), the analysis method or approach used, and the required solutions to be achieved (outputs) (Asmaa, 2014).

All the previous tests, whether on paper or in Excel sheets, were collected. Data was also collected from previous geotechnical investigation reports. The data collected was then consolidated into inputs and outputs. This information was crucial to designing the initial database because this was the exact data that was planned to be stored in it.

The South African Pavement Engineering Manual (SAPEM) specifically described the tests required for proper geotechnical investigations and highlighted the necessary outputs from these tests. The outputs require specific manipulation to give values or descriptions of the soil that assist the engineer in making vital decisions for design.

4.2 Evaluating Available Geotechnical Information Systems and Databases

Available geotechnical information systems were thoroughly assessed to determine if these systems provided the specific requirements of an ISGE, specifically in South Africa. Specific criteria were used to assess these systems.

These systems need to have storage functionality. Databases provide this type of functionality which allows the user to store, manage and update data. The database also requires relating all forms of data fields to other data fields. This is called a relational database. Relating different test results and readings to a specific test pit, layer, or site will significantly improve the ability of the ISGE to improve decision making through a more efficient comparison of these values.

4.3 Designing and Creating the ISGE

4.3.1 Information system for geotechnical engineers

The system was created based on the requirements of an ISGE. It was made to store data (through the database) and link the stored data to the interface that transforms the data into information through queries. The tables in the databases (all linked to the sample data table) were linked to their respective worksheets on the interface and linked to the final summary page. The summary page shows all the essential information from each laboratory test and assesses the results to assist in decision-making. All the accumulated data can be exported in file formats that could be used to compare data in a GIS environment. Figure 28 shows the relationships between each component of the ISGE.

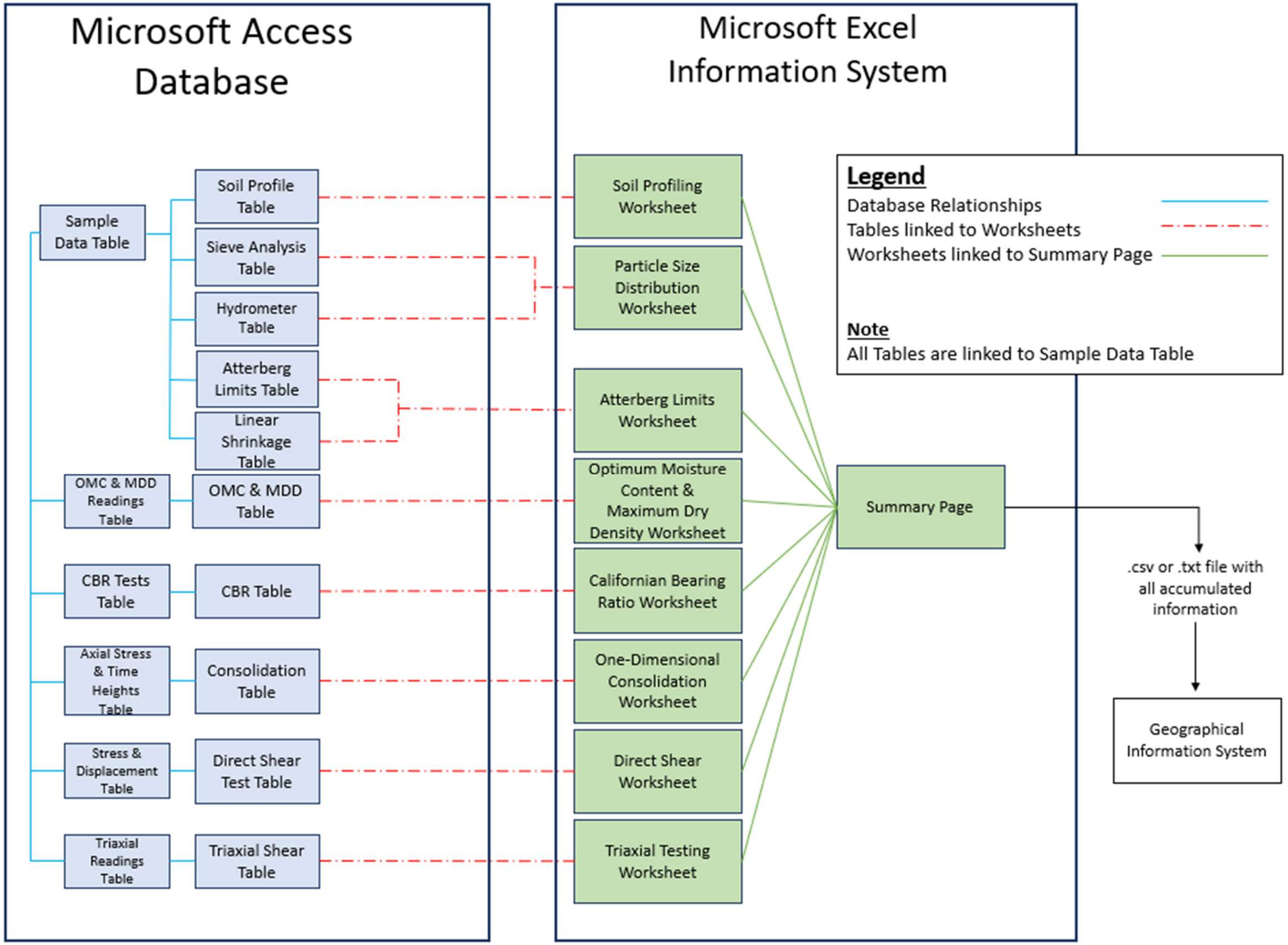


Figure 28 – Detailed layout of components in the ISGE

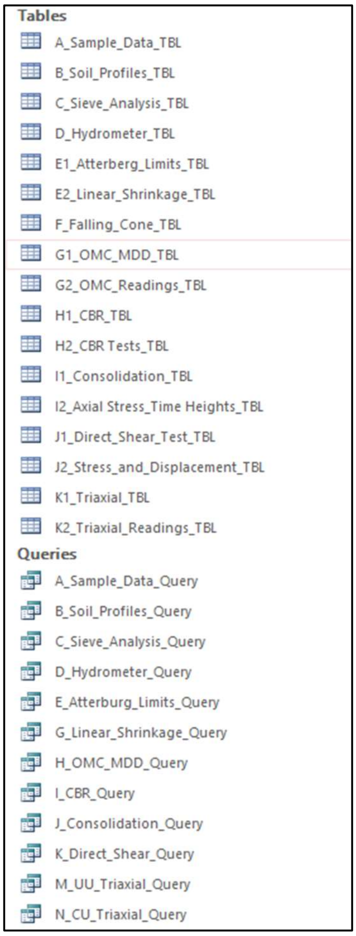
4.3.2 Microsoft Access

Microsoft Access was used to create a database to store all the data and information of the selected tests. Microsoft Access was based on the ease of use and general accessibility of Microsoft Office tools to professionals expected to make use of this software.

Microsoft Access, although not as efficient as Structured Query Language (SQL), the alternative well-established database server, it presented an easier method of building the baseline of the database for the ISGE. SQL is expensive to run and is usually used when a large number of users need to access it. The baseline design of the ISGE database needs to first be built according to its requirements. Access is less expensive and can be used within a small group of people during its development. Microsoft has designed functionality for the Access database to easily be imported into a SQL server for further development. This will allow the database to develop further in SQL if the database becomes accessible to a larger scale of engineers and becomes economically viable to transition to a larger database.

Microsoft Access and Excel (which was used to design the interface and perform the more advanced calculations and charting) are designed by Microsoft to link effectively. Microsoft Office also has the advantage of Visual Basic for Applications (VBA) which allows automation and improved customization. In Chapter 3, it was also shown that the software programs regularly export their files back into Microsoft software formats as these formats are often used for reporting.

The Microsoft Access database was made with tables, fields, records, queries and forms. For each of the required tests, a table was made with fields for each of the inputs. Each of the tables was organized using letters at the beginning of each name. The letters were used to sort them in alphabetical order for organizational purposes (shown in Figure 29):



Tables
A_Sample_Data_TBL
B_Soil_Profiles_TBL
C_Sieve_Analysis_TBL
D_Hydrometer_TBL
E1_Atterberg_Limits_TBL
E2_Linear_Shrinkage_TBL
F_Falling_Cone_TBL
G1_OMC_MDD_TBL
G2_OMC_Readings_TBL
H1_CBR_TBL
H2_CBR Tests_TBL
I1_Consolidation_TBL
I2_Axial Stress_Time Heights_TBL
J1_Direct_Shear_Test_TBL
J2_Stress_and_Displacement_TBL
K1_Triaxial_TBL
K2_Triaxial_Readings_TBL
Queries
A_Sample_Data_Query
B_Soil_Profiles_Query
C_Sieve_Analysis_Query
D_Hydrometer_Query
E_Atterburg_Limits_Query
G_Linear_Shrinkage_Query
H_OMC_MDD_Query
I_CBR_Query
J_Consolidation_Query
K_Direct_Shear_Query
M_UU_Triaxial_Query
N_CU_Triaxial_Query

Figure 29 – Tables and queries in Microsoft Access

These tables with the relationships were the foundation of the database. Each of these tables with the fields and records allows querying of data for analysis. This is significant to the information system that requires certain information from several tables to perform certain manipulations or when a decision needs to be made using specific data from multiple tests. For this reason, queries were made which were used by the information system. The relationships between all the tables within the database are shown in Figure 30 below. In addition, all the main tables were linked to the Sample Data table to allow any sample and any related information to be queried.

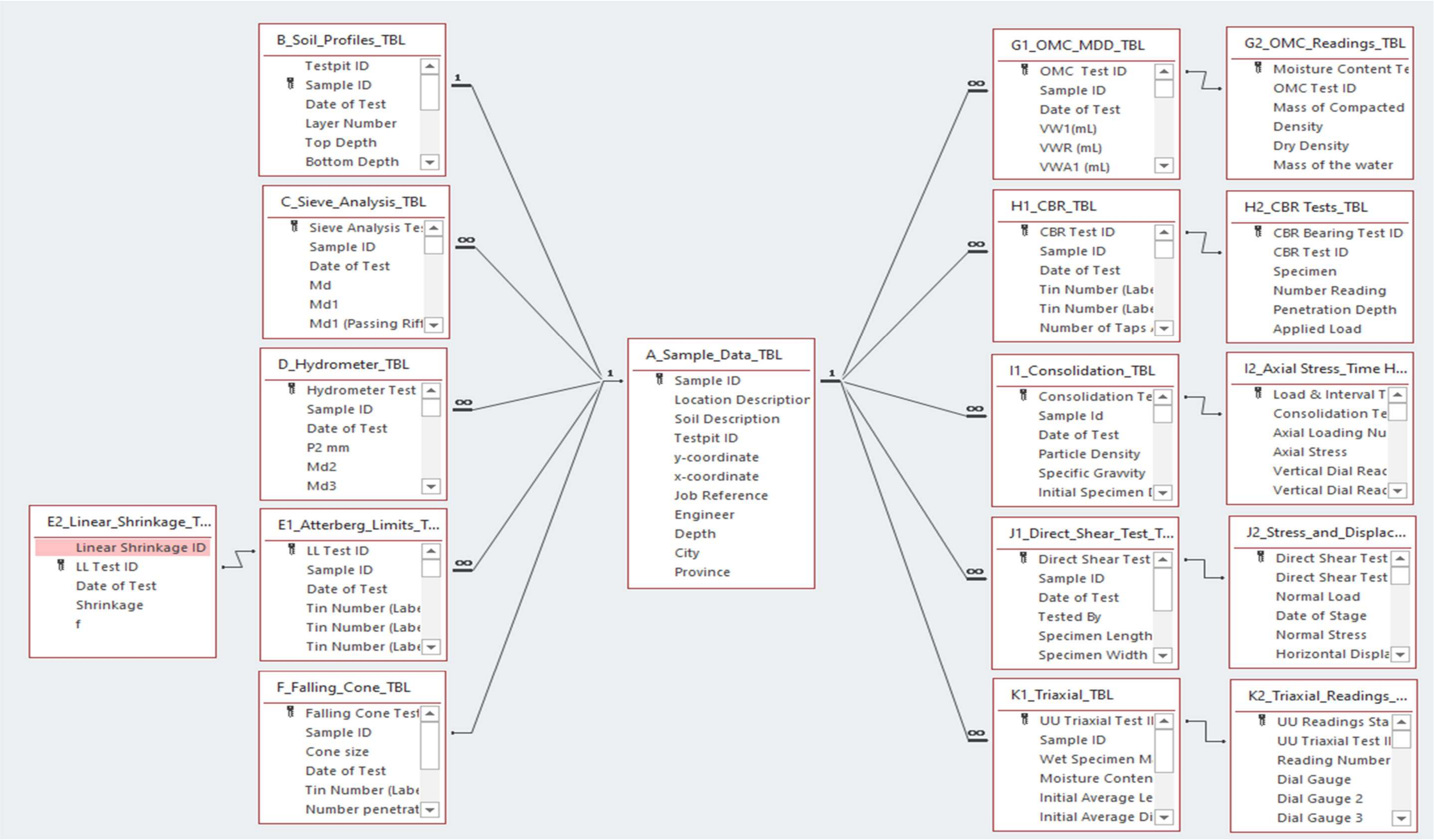


Figure 30 – Relationships of tables within the Microsoft Access database

4.3.3 Designing the database components

Databases consist primarily of records, fields, tables and queries (see Chapter 3). One-to-many and one-to-one relationships were also needed to build the database.

The data collected was categorised into specific tests. The first step of the database design was to design the tables. The tables were made for each laboratory test or any category of geotechnical investigations that needed to be used by the ISGE Interface. The first table designed was a table that stores the important information about the sample. This first table became the central table from which most tables were directly or indirectly related. This was used for filtering and querying purposes.

Secondly, fields were created in each table to allow each record to produce the correct information. The most important fields were the primary keys, which distinguish the test, and the field that related the test to a specific sample, the foreign key. The rest of the fields corresponded with the required inputs of each test/category.

Relationships are vital to preventing data loss and were required to make the database a relational database management system (RDMS). Once the tables with their fields had been created, they needed to be linked through relationships. Most tables were related to the sample information table. The relationships between the tables and the sample information table allowed each sample to have more than one result. These relationships are called one-to-many relationships. Some tests required two or more tables to allow for tests that produce multiple values within the same procedure. This was done by making parent tables that provide the key information for the tests with a child table linked to the parent table to allow multiple records to relate to the test procedure indicated in the parent table. These relationships between the parent test table and the second table were designed as one-to-many relationships as well.

After the relationships had been created, the core database was completed. The final part of the database design would be the creation of queries. These were, however, designed after the ISGE Interface. The reason for this was that the ISGE Interface would require specific information from several tables for each test interface and the summary page. These specific queries could not be designed before the interface had been completed. When the initial ISGE had been completed, the database was re-evaluated to fix any underlying issues with the database's components.

4.4 Designing and Creating the Proposed ISGE Interface

Microsoft Excel was used for the design of the ISGE. As with Microsoft Access, it is readily accessible for most engineers in South Africa with the potential to design professional interfaces, perform advanced engineering calculations and produce accurate outputs as required by the engineer. Excel can be linked to the Access database for effective manipulation of the data stored in it. The capacity of macros and VBA with Excel allows for better manipulation and automation of the system. The ISGE interface has been designed for output generation but not for any data storage. The outputs required were discussed earlier in this chapter.

The ISGE interface consists of several main entities. These entities include a workbook, worksheets, cells, formulas, macros and VBA code (see Chapter 2). A workbook was compiled with several worksheets to make the functional interface for the ISGE.

A worksheet was created for each test or geotechnical engineering application. The following approach was used to design each sheet:

i. Determine all inputs

Each test was carefully studied to determine the values recorded during the test. These input values also include criteria that describe the test procedure used. Using the correct units was necessary and these were therefore implemented.

ii. Determine all outputs

The expected results were established. These include any charts, values analysis or predictions required from the completion of the test procedure performed. Several tests have extra results or analyses that are used in everyday practice but were not necessarily prescribed by the codes. These values or analyses were additionally used as outputs. Using the correct units was compulsory and these were therefore implemented.

iii. Write formulas

All formulas were then composed for the manipulation of the input values into the necessary results. The formulas stated in the standards or codes were used for this manipulation. The formulas for outputs additional to the standards were also entered. Some results required more advanced mathematical formulas to be determined through methods that were usually interpreted by hand.

iv. Create charts and results

All visual outputs such as charts or graphs were then created using the results of the tests. Some of these visual outputs are necessary for further interpreted results. For example, formulas were used to determine values that would have been read from the charts on paper. These values were then added to the graphs to display the indicators that would otherwise have been used to determine the values on paper in a reverse engineering manner.

v. Initial layout

The layout of the sheet was developed to display all the input, values and formulas required to process the results and outputs. The core reason for the interface's layout was to display all the information clearly and accurately. In addition, it was designed to be user-friendly while remaining professional. The general aesthetic of the sheets (including charts) was also designed and applied to all the sheets to make the ISGE uniform in presentation.

vi. Testing interface

The interface was then tested using example values from the standards' examples. Finally, the results were compared, and the formulas were corrected where necessary. Real test values were then tested; however, many laboratories use additional standards within their regulations, making some values very difficult to enter or interpret. The sheets were adapted for many of these variations, but the unnecessary variations were omitted from the sheet.

The data was then linked to the Excel sheet of the ISGE to allow the user to compare and transform the data to make informative decisions.

vii. Create a summary page

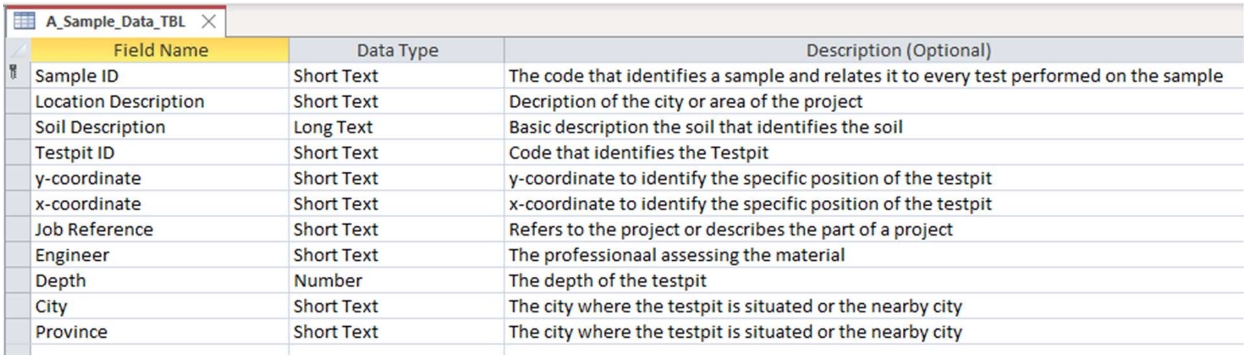
The final part of the ISGE interface was the summary page, where the overall results and analysis of a sample were summarised. In addition, the page was made to display all the important results from the tests.

viii. File exportation

An option to export a .csv or .txt file was also created for use in geographical systems to compare the geotechnical properties of the soils in areas. With the summary page, this feature could assist the engineer when making decisions during the desktop study phase.

4.4.1 Sample data

The first table made was the Sample Data table. The most important information for samples, especially during site investigations and identifying samples afterwards while testing or writing the reports, were stored in this table. The information (especially the coordinates) would benefit future users in GIS or any form of locational identification. This table was linked to every main table through the primary key Sample ID. Figure 31 below shows the structure of the Sample Data table with descriptions.

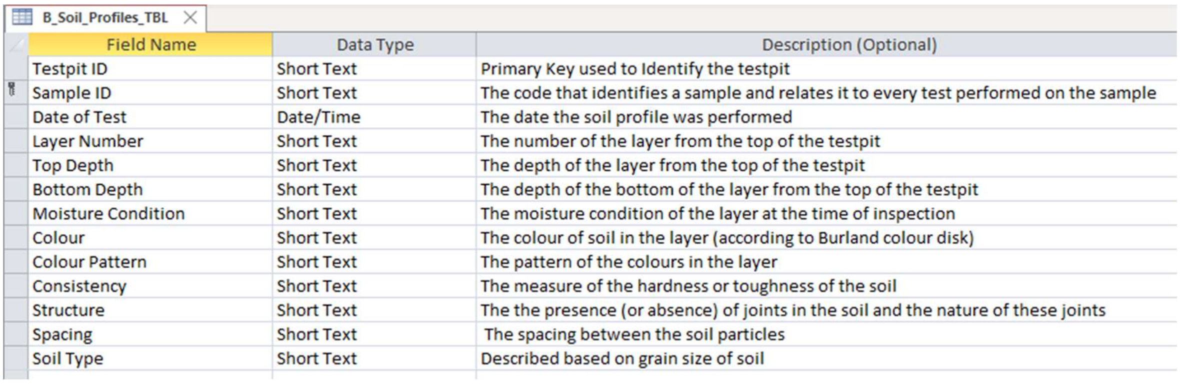


Field Name	Data Type	Description (Optional)
Sample ID	Short Text	The code that identifies a sample and relates it to every test performed on the sample
Location Description	Short Text	Decription of the city or area of the project
Soil Description	Long Text	Basic description the soil that identifies the soil
Testpit ID	Short Text	Code that identifies the Testpit
y-coordinate	Short Text	y-coordinate to identify the specific position of the testpit
x-coordinate	Short Text	x-coordinate to identify the specific position of the testpit
Job Reference	Short Text	Refers to the project or describes the part of a project
Engineer	Short Text	The professionaal assessing the material
Depth	Number	The depth of the testpit
City	Short Text	The city where the testpit is situated or the nearby city
Province	Short Text	The city where the testpit is situated or the nearby city

Figure 31 – Sample data database table

4.4.2 Soil profiles

The next table was the Soil Profiles table containing all the information collected on-site. It described each layer of the soil profile. This table contains the descriptive properties for the test pit layers on site as suggested by the SAICE code of Practice. This table allowed each layer to be described as a record. Figure 32 below shows the structure of the Soil Profiles table with descriptions.

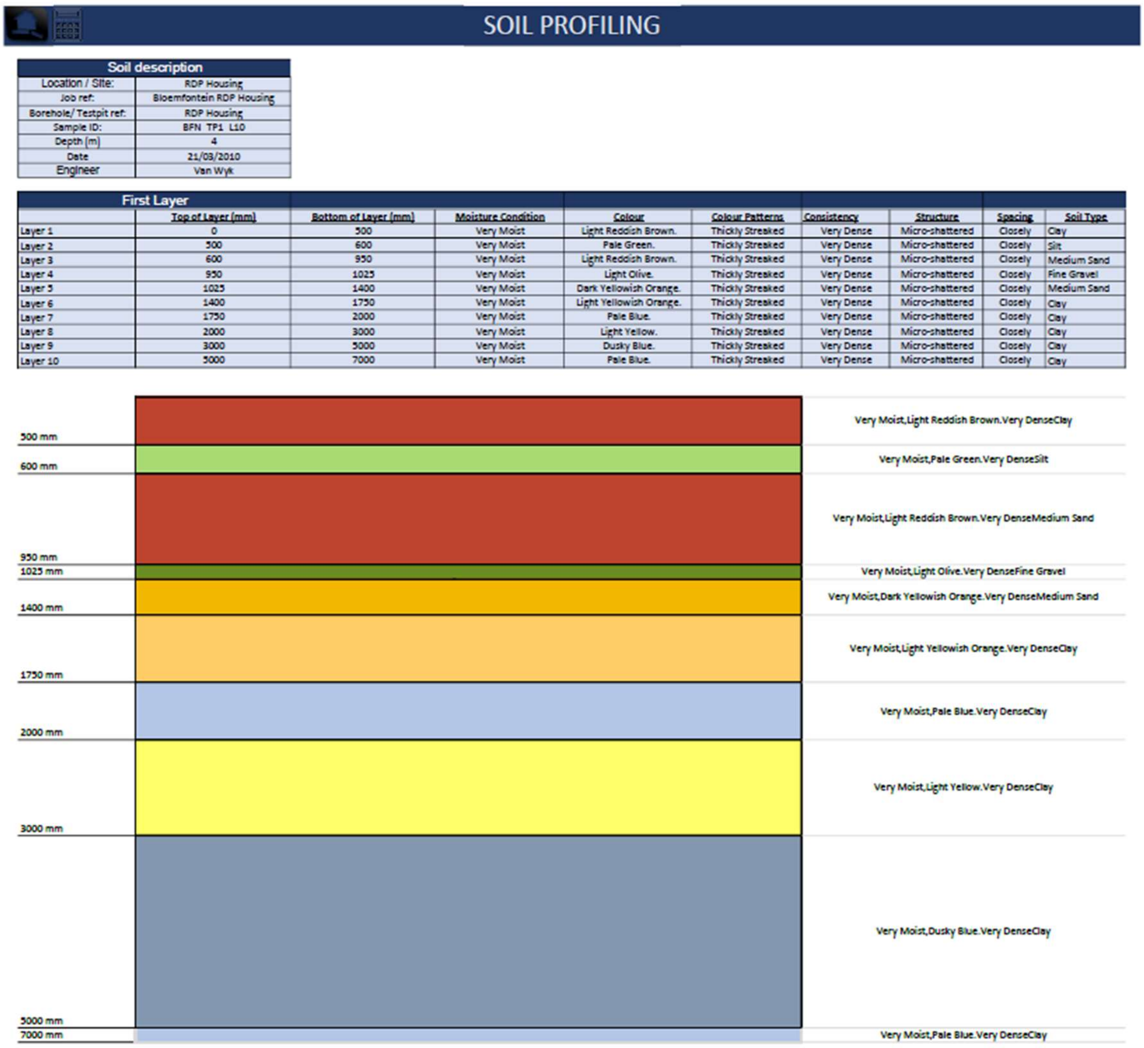


B_Soil_Profiles_TBL

Field Name	Data Type	Description (Optional)
Testpit ID	Short Text	Primary Key used to Identify the testpit
Sample ID	Short Text	The code that identifies a sample and relates it to every test performed on the sample
Date of Test	Date/Time	The date the soil profile was performed
Layer Number	Short Text	The number of the layer from the top of the testpit
Top Depth	Short Text	The depth of the layer from the top of the testpit
Bottom Depth	Short Text	The depth of the bottom of the layer from the top of the testpit
Moisture Condition	Short Text	The moisture condition of the layer at the time of inspection
Colour	Short Text	The colour of soil in the layer (according to Burland colour disk)
Colour Pattern	Short Text	The pattern of the colours in the layer
Consistency	Short Text	The measure of the hardness or toughness of the soil
Structure	Short Text	The the presence (or absence) of joints in the soil and the nature of these joints
Spacing	Short Text	The spacing between the soil particles
Soil Type	Short Text	Described based on grain size of soil

Figure 32 – Soil profiles database table

The soil profiling table was connected to the soil profile worksheet in the user interface, where the data was shown in layers of a specific test. The table lays out every layer describing all the criteria of each layer. These layers are illustrated in Figure 33 below, with the layers being automatically adjusted to give the engineer a good impression of the heights and give descriptions alongside. The reason why colours were used and not patterns described by the SAICE Code of Practice was due to patterns not being customisable in Microsoft Excel.



SOIL PROFILING

Soil description	
Location / Site:	RDP Housing
Job ref:	Bloemfontein RDP Housing
Borehole/ Testpit ref:	RDP Housing
Sample ID:	BFN TP1 L10
Depth (m)	4
Date	21/03/2010
Engineer	Van Wyk

First Layer

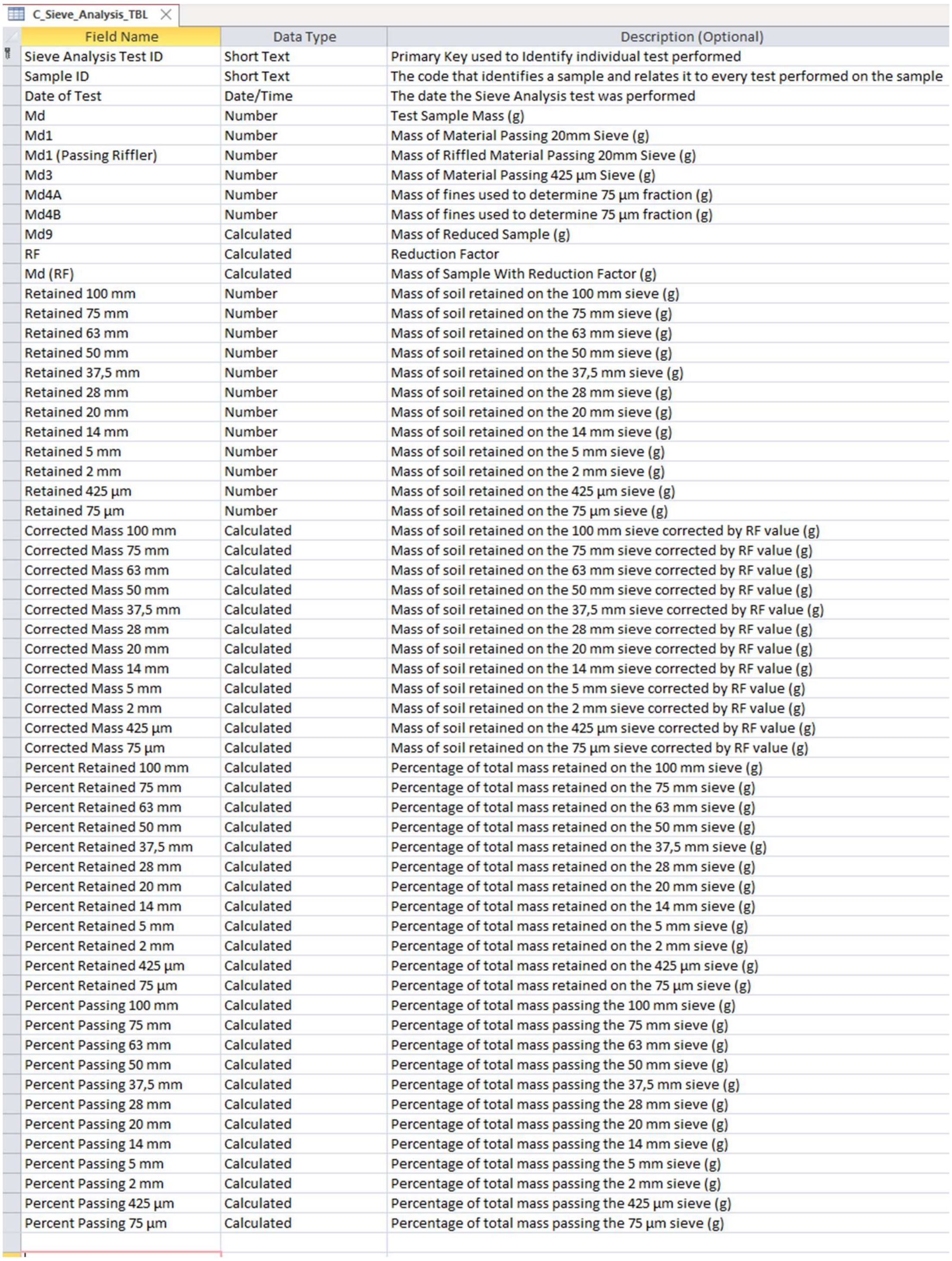
	Top of Layer (mm)	Bottom of Layer (mm)	Moisture Condition	Colour	Colour Patterns	Consistency	Structure	Spacing	Soil Type
Layer 1	0	500	Very Moist	Light Reddish Brown.	Thickly Streaked	Very Dense	Micro-shattered	Closely	Clay
Layer 2	500	600	Very Moist	Pale Green.	Thickly Streaked	Very Dense	Micro-shattered	Closely	Silt
Layer 3	600	950	Very Moist	Light Reddish Brown.	Thickly Streaked	Very Dense	Micro-shattered	Closely	Medium Sand
Layer 4	950	1025	Very Moist	Light Olive.	Thickly Streaked	Very Dense	Micro-shattered	Closely	Fine Gravel
Layer 5	1025	1400	Very Moist	Dark Yellowish Orange.	Thickly Streaked	Very Dense	Micro-shattered	Closely	Medium Sand
Layer 6	1400	1750	Very Moist	Light Yellowish Orange.	Thickly Streaked	Very Dense	Micro-shattered	Closely	Clay
Layer 7	1750	2000	Very Moist	Pale Blue.	Thickly Streaked	Very Dense	Micro-shattered	Closely	Clay
Layer 8	2000	3000	Very Moist	Light Yellow.	Thickly Streaked	Very Dense	Micro-shattered	Closely	Clay
Layer 9	3000	5000	Very Moist	Dusky Blue.	Thickly Streaked	Very Dense	Micro-shattered	Closely	Clay
Layer 10	5000	7000	Very Moist	Pale Blue.	Thickly Streaked	Very Dense	Micro-shattered	Closely	Clay

Figure 33 – Soil Profiles worksheet

4.4.3 Particle size distribution

Particle size distribution is determined through three SANS3001 codes, namely the sieve analysis (wet preparation and dry preparation) and the hydrometer method. These tests have been added into one worksheet but were separated into different tables in the database.

The first table of the SANS3001 was the sieve analysis (SANS3001 GR1 and GR2). This table (Figure 34) contains all the information required before, during and after the test. This table was focused on the primary information while showing all the steps from retained material to calculating the corrected mass percentage retained and the percentage passing.



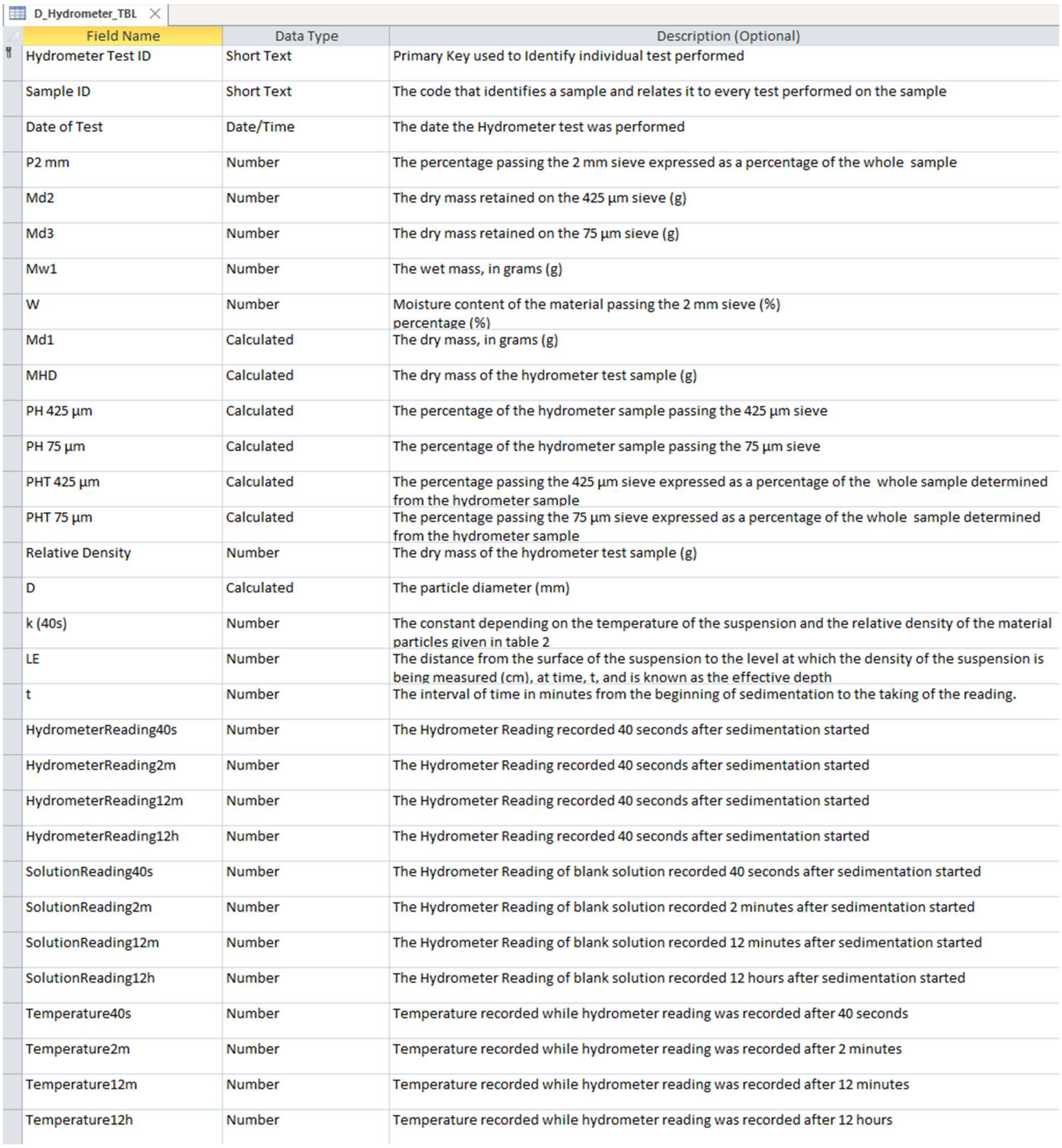
C_Sieve_Analysis_TBL

Field Name	Data Type	Description (Optional)
Sieve Analysis Test ID	Short Text	Primary Key used to Identify individual test performed
Sample ID	Short Text	The code that identifies a sample and relates it to every test performed on the sample
Date of Test	Date/Time	The date the Sieve Analysis test was performed
Md	Number	Test Sample Mass (g)
Md1	Number	Mass of Material Passing 20mm Sieve (g)
Md1 (Passing Riffler)	Number	Mass of Riffled Material Passing 20mm Sieve (g)
Md3	Number	Mass of Material Passing 425 µm Sieve (g)
Md4A	Number	Mass of fines used to determine 75 µm fraction (g)
Md4B	Number	Mass of fines used to determine 75 µm fraction (g)
Md9	Calculated	Mass of Reduced Sample (g)
RF	Calculated	Reduction Factor
Md (RF)	Calculated	Mass of Sample With Reduction Factor (g)
Retained 100 mm	Number	Mass of soil retained on the 100 mm sieve (g)
Retained 75 mm	Number	Mass of soil retained on the 75 mm sieve (g)
Retained 63 mm	Number	Mass of soil retained on the 63 mm sieve (g)
Retained 50 mm	Number	Mass of soil retained on the 50 mm sieve (g)
Retained 37,5 mm	Number	Mass of soil retained on the 37,5 mm sieve (g)
Retained 28 mm	Number	Mass of soil retained on the 28 mm sieve (g)
Retained 20 mm	Number	Mass of soil retained on the 20 mm sieve (g)
Retained 14 mm	Number	Mass of soil retained on the 14 mm sieve (g)
Retained 5 mm	Number	Mass of soil retained on the 5 mm sieve (g)
Retained 2 mm	Number	Mass of soil retained on the 2 mm sieve (g)
Retained 425 µm	Number	Mass of soil retained on the 425 µm sieve (g)
Retained 75 µm	Number	Mass of soil retained on the 75 µm sieve (g)
Corrected Mass 100 mm	Calculated	Mass of soil retained on the 100 mm sieve corrected by RF value (g)
Corrected Mass 75 mm	Calculated	Mass of soil retained on the 75 mm sieve corrected by RF value (g)
Corrected Mass 63 mm	Calculated	Mass of soil retained on the 63 mm sieve corrected by RF value (g)
Corrected Mass 50 mm	Calculated	Mass of soil retained on the 50 mm sieve corrected by RF value (g)
Corrected Mass 37,5 mm	Calculated	Mass of soil retained on the 37,5 mm sieve corrected by RF value (g)
Corrected Mass 28 mm	Calculated	Mass of soil retained on the 28 mm sieve corrected by RF value (g)
Corrected Mass 20 mm	Calculated	Mass of soil retained on the 20 mm sieve corrected by RF value (g)
Corrected Mass 14 mm	Calculated	Mass of soil retained on the 14 mm sieve corrected by RF value (g)
Corrected Mass 5 mm	Calculated	Mass of soil retained on the 5 mm sieve corrected by RF value (g)
Corrected Mass 2 mm	Calculated	Mass of soil retained on the 2 mm sieve corrected by RF value (g)
Corrected Mass 425 µm	Calculated	Mass of soil retained on the 425 µm sieve corrected by RF value (g)
Corrected Mass 75 µm	Calculated	Mass of soil retained on the 75 µm sieve corrected by RF value (g)
Percent Retained 100 mm	Calculated	Percentage of total mass retained on the 100 mm sieve (g)
Percent Retained 75 mm	Calculated	Percentage of total mass retained on the 75 mm sieve (g)
Percent Retained 63 mm	Calculated	Percentage of total mass retained on the 63 mm sieve (g)
Percent Retained 50 mm	Calculated	Percentage of total mass retained on the 50 mm sieve (g)
Percent Retained 37,5 mm	Calculated	Percentage of total mass retained on the 37,5 mm sieve (g)
Percent Retained 28 mm	Calculated	Percentage of total mass retained on the 28 mm sieve (g)
Percent Retained 20 mm	Calculated	Percentage of total mass retained on the 20 mm sieve (g)
Percent Retained 14 mm	Calculated	Percentage of total mass retained on the 14 mm sieve (g)
Percent Retained 5 mm	Calculated	Percentage of total mass retained on the 5 mm sieve (g)
Percent Retained 2 mm	Calculated	Percentage of total mass retained on the 2 mm sieve (g)
Percent Retained 425 µm	Calculated	Percentage of total mass retained on the 425 µm sieve (g)
Percent Retained 75 µm	Calculated	Percentage of total mass retained on the 75 µm sieve (g)
Percent Passing 100 mm	Calculated	Percentage of total mass passing the 100 mm sieve (g)
Percent Passing 75 mm	Calculated	Percentage of total mass passing the 75 mm sieve (g)
Percent Passing 63 mm	Calculated	Percentage of total mass passing the 63 mm sieve (g)
Percent Passing 50 mm	Calculated	Percentage of total mass passing the 50 mm sieve (g)
Percent Passing 37,5 mm	Calculated	Percentage of total mass passing the 37,5 mm sieve (g)
Percent Passing 28 mm	Calculated	Percentage of total mass passing the 28 mm sieve (g)
Percent Passing 20 mm	Calculated	Percentage of total mass passing the 20 mm sieve (g)
Percent Passing 14 mm	Calculated	Percentage of total mass passing the 14 mm sieve (g)
Percent Passing 5 mm	Calculated	Percentage of total mass passing the 5 mm sieve (g)
Percent Passing 2 mm	Calculated	Percentage of total mass passing the 2 mm sieve (g)
Percent Passing 425 µm	Calculated	Percentage of total mass passing the 425 µm sieve (g)
Percent Passing 75 µm	Calculated	Percentage of total mass passing the 75 µm sieve (g)

Figure 34 – Sieve analysis database table

4.4.4 Hydrometer

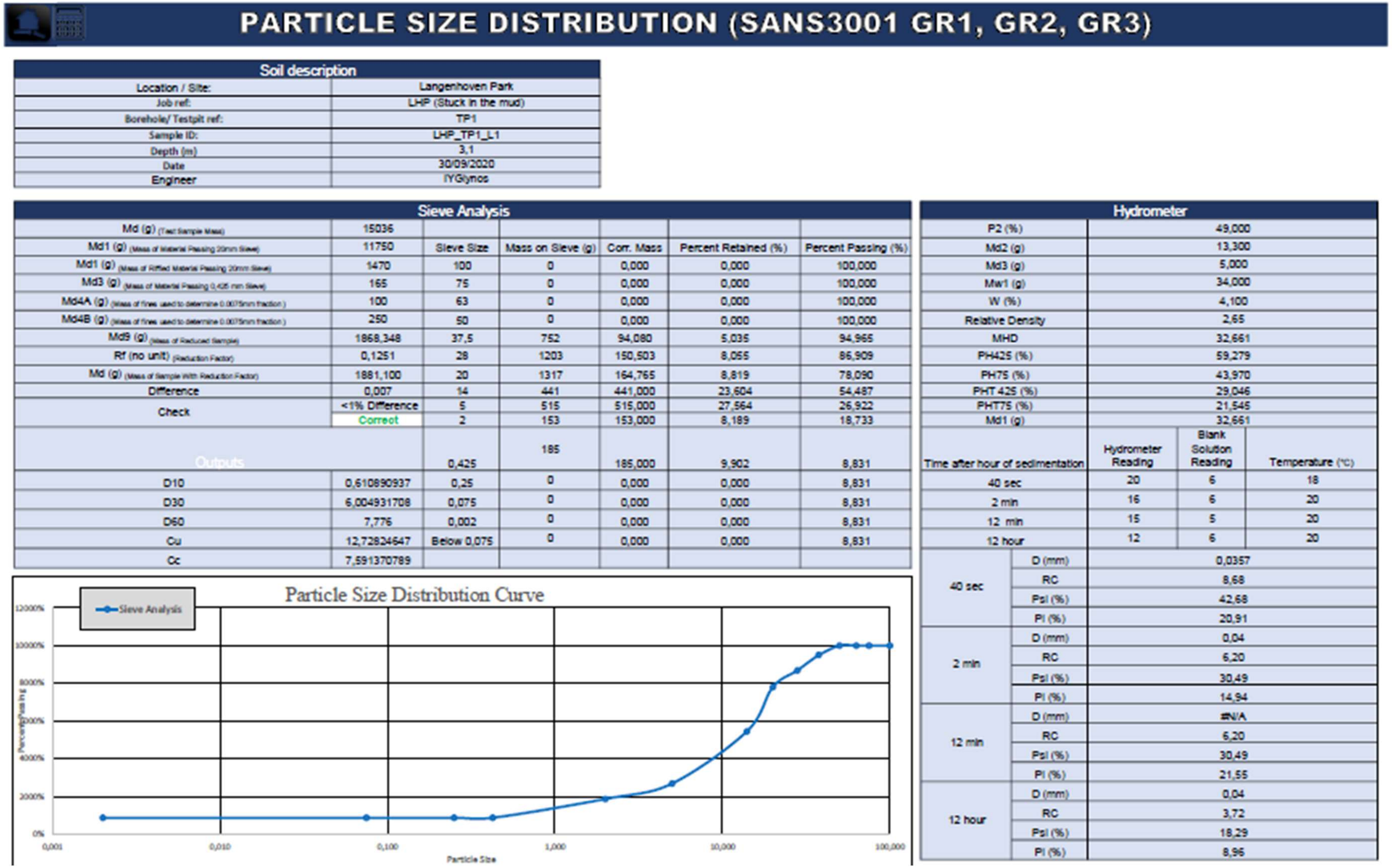
The following table created was the hydrometer tests table from the SANS3001 GR3. This table allowed predetermined input values and the values for the 40 seconds, 2 minutes, 12 minutes, and 12 hours readings. In addition, each specified time had hydrometer reading, blank solution reading and temperature reading fields. These were the values required to determine the particle size and percentage. The table (Figure 35) does not calculate the outputs as these calculations were better suited for Microsoft Excel and therefore calculated the information system interface.



Field Name	Data Type	Description (Optional)
Hydrometer Test ID	Short Text	Primary Key used to Identify individual test performed
Sample ID	Short Text	The code that identifies a sample and relates it to every test performed on the sample
Date of Test	Date/Time	The date the Hydrometer test was performed
P2 mm	Number	The percentage passing the 2 mm sieve expressed as a percentage of the whole sample
Md2	Number	The dry mass retained on the 425 µm sieve (g)
Md3	Number	The dry mass retained on the 75 µm sieve (g)
Mw1	Number	The wet mass, in grams (g)
W	Number	Moisture content of the material passing the 2 mm sieve (%) percentage (%)
Md1	Calculated	The dry mass, in grams (g)
MHD	Calculated	The dry mass of the hydrometer test sample (g)
PH 425 µm	Calculated	The percentage of the hydrometer sample passing the 425 µm sieve
PH 75 µm	Calculated	The percentage of the hydrometer sample passing the 75 µm sieve
PHT 425 µm	Calculated	The percentage passing the 425 µm sieve expressed as a percentage of the whole sample determined from the hydrometer sample
PHT 75 µm	Calculated	The percentage passing the 75 µm sieve expressed as a percentage of the whole sample determined from the hydrometer sample
Relative Density	Number	The dry mass of the hydrometer test sample (g)
D	Calculated	The particle diameter (mm)
k (40s)	Number	The constant depending on the temperature of the suspension and the relative density of the material particles given in table 2
LE	Number	The distance from the surface of the suspension to the level at which the density of the suspension is being measured (cm), at time, t, and is known as the effective depth
t	Number	The interval of time in minutes from the beginning of sedimentation to the taking of the reading.
HydrometerReading40s	Number	The Hydrometer Reading recorded 40 seconds after sedimentation started
HydrometerReading2m	Number	The Hydrometer Reading recorded 40 seconds after sedimentation started
HydrometerReading12m	Number	The Hydrometer Reading recorded 40 seconds after sedimentation started
HydrometerReading12h	Number	The Hydrometer Reading recorded 40 seconds after sedimentation started
SolutionReading40s	Number	The Hydrometer Reading of blank solution recorded 40 seconds after sedimentation started
SolutionReading2m	Number	The Hydrometer Reading of blank solution recorded 2 minutes after sedimentation started
SolutionReading12m	Number	The Hydrometer Reading of blank solution recorded 12 minutes after sedimentation started
SolutionReading12h	Number	The Hydrometer Reading of blank solution recorded 12 hours after sedimentation started
Temperature40s	Number	Temperature recorded while hydrometer reading was recorded after 40 seconds
Temperature2m	Number	Temperature recorded while hydrometer reading was recorded after 2 minutes
Temperature12m	Number	Temperature recorded while hydrometer reading was recorded after 12 minutes
Temperature12h	Number	Temperature recorded while hydrometer reading was recorded after 12 hours

Figure 35 – Hydrometer database table

The particle size distribution worksheet transforms all the input data from both sheets and produces the required outputs, as explained in Chapter 2. The primary outputs were the particle sizes and the percentage of soil passing the sieves, producing another output, the particle size distribution curve. Figure 36 shows the worksheet for the particle size distribution.



PARTICLE SIZE DISTRIBUTION (SANS3001 GR1, GR2, GR3)

Soil description	
Location / Site:	Langenhoven Park
Job ref:	LHP (Stuck in the mud)
Borehole/ Testpit ref:	TP1
Sample ID:	LHP_TP1_L1
Depth (m)	3,1
Date	30/09/2020
Engineer	IYGlynos

Sieve Analysis

Md (g) (Test Sample Mass)	15036					
Md1 (g) (Mass of Material Passing 20mm Sieve)	11750	Sieve Size	Mass on Sieve (g)	Corr. Mass	Percent Retained (%)	Percent Passing (%)
Md1 (g) (Mass of Riffled Material Passing 20mm Sieve)	1470	100	0	0,000	0,000	100,000
Md3 (g) (Mass of Material Passing 0,425 mm Sieve)	165	75	0	0,000	0,000	100,000
Md4A (g) (Mass of fines used to determine 0.0075mm fraction)	100	63	0	0,000	0,000	100,000
Md4B (g) (Mass of fines used to determine 0.0075mm fraction)	250	50	0	0,000	0,000	100,000
Md9 (g) (Mass of Reduced Sample)	1868,348	37,5	752	94,080	5,035	94,965
Rf (no unit) (Reduction Factor)	0,1251	28	1203	150,503	8,055	86,909
Md (g) (Mass of Sample With Reduction Factor)	1881,100	20	1317	164,765	8,819	78,090
Difference	0,007	14	441	441,000	23,604	54,487
Check	<1% Difference	5	515	515,000	27,564	26,922
	Correct	2	153	153,000	8,189	18,733
Outputs		0,425	185	185,000	9,902	8,831
D10	0,610890937	0,25	0	0,000	0,000	8,831
D30	6,004931708	0,075	0	0,000	0,000	8,831
D60	7,776	0,002	0	0,000	0,000	8,831
Cu	12,72824647	Below 0,075	0	0,000	0,000	8,831
Cc	7,591370789					

Particle Size Distribution Curve

Hydrometer

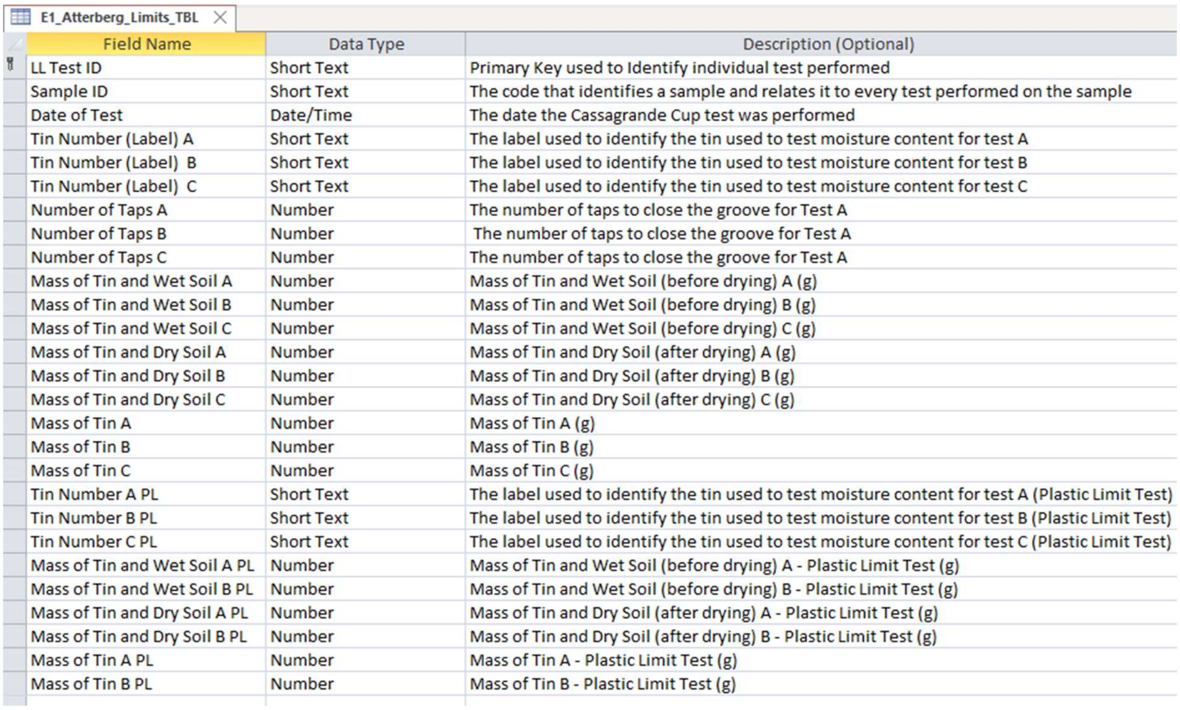
P2 (%)	49,000		
Md2 (g)	13,300		
Md3 (g)	5,000		
Mw1 (g)	34,000		
W (%)	4,100		
Relative Density	2,65		
MHD	32,661		
PH425 (%)	59,279		
PH75 (%)	43,970		
PHT 425 (%)	29,046		
PHT75 (%)	21,545		
Md1 (g)	32,661		
Time after hour of sedimentation	Hydrometer Reading	Blank Solution Reading	Temperature (°C)
40 sec	20	6	18
2 min	16	6	20
12 min	15	5	20
12 hour	12	6	20

40 sec	D (mm)	0,0357
	RC	8,68
	Psl (%)	42,68
	PI (%)	20,91
2 min	D (mm)	0,04
	RC	6,20
	Psl (%)	30,49
	PI (%)	14,94
12 min	D (mm)	#N/A
	RC	6,20
	Psl (%)	30,49
	PI (%)	21,55
12 hour	D (mm)	0,04
	RC	3,72
	Psl (%)	18,29
	PI (%)	8,96

Figure 36 – Particle size and hydrometer worksheet

4.4.5 Atterberg limits (Casagrande method)

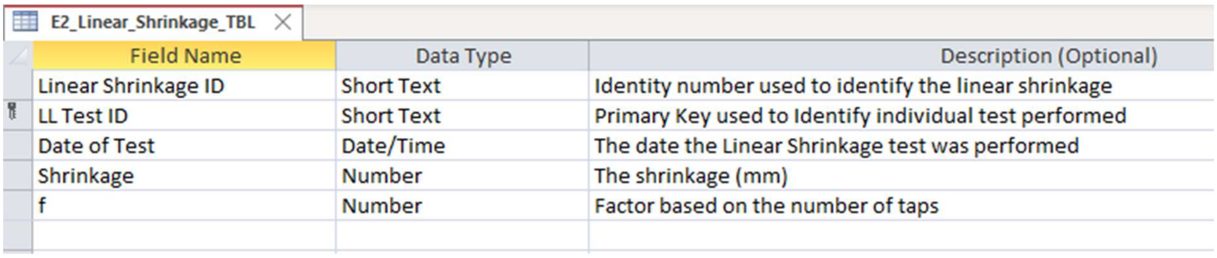
The Atterberg limits table included the inputs for the plastic limit, the liquid limit and the plastic index. The SANS3001 GR10, GR11 and GR12 determine the Atterberg limits. Instead of creating multiple separate tables for the required multiple sample tests performed for these codes, one table (Figure 37) was created with the capacity to allow three sets of test data (inputs and outputs) to be stored.



Field Name	Data Type	Description (Optional)
LL Test ID	Short Text	Primary Key used to Identify individual test performed
Sample ID	Short Text	The code that identifies a sample and relates it to every test performed on the sample
Date of Test	Date/Time	The date the Cassagrande Cup test was performed
Tin Number (Label) A	Short Text	The label used to identify the tin used to test moisture content for test A
Tin Number (Label) B	Short Text	The label used to identify the tin used to test moisture content for test B
Tin Number (Label) C	Short Text	The label used to identify the tin used to test moisture content for test C
Number of Taps A	Number	The number of taps to close the groove for Test A
Number of Taps B	Number	The number of taps to close the groove for Test A
Number of Taps C	Number	The number of taps to close the groove for Test A
Mass of Tin and Wet Soil A	Number	Mass of Tin and Wet Soil (before drying) A (g)
Mass of Tin and Wet Soil B	Number	Mass of Tin and Wet Soil (before drying) B (g)
Mass of Tin and Wet Soil C	Number	Mass of Tin and Wet Soil (before drying) C (g)
Mass of Tin and Dry Soil A	Number	Mass of Tin and Dry Soil (after drying) A (g)
Mass of Tin and Dry Soil B	Number	Mass of Tin and Dry Soil (after drying) B (g)
Mass of Tin and Dry Soil C	Number	Mass of Tin and Dry Soil (after drying) C (g)
Mass of Tin A	Number	Mass of Tin A (g)
Mass of Tin B	Number	Mass of Tin B (g)
Mass of Tin C	Number	Mass of Tin C (g)
Tin Number A PL	Short Text	The label used to identify the tin used to test moisture content for test A (Plastic Limit Test)
Tin Number B PL	Short Text	The label used to identify the tin used to test moisture content for test B (Plastic Limit Test)
Tin Number C PL	Short Text	The label used to identify the tin used to test moisture content for test C (Plastic Limit Test)
Mass of Tin and Wet Soil A PL	Number	Mass of Tin and Wet Soil (before drying) A - Plastic Limit Test (g)
Mass of Tin and Wet Soil B PL	Number	Mass of Tin and Wet Soil (before drying) B - Plastic Limit Test (g)
Mass of Tin and Dry Soil A PL	Number	Mass of Tin and Dry Soil (after drying) A - Plastic Limit Test (g)
Mass of Tin and Dry Soil B PL	Number	Mass of Tin and Dry Soil (after drying) B - Plastic Limit Test (g)
Mass of Tin A PL	Number	Mass of Tin A - Plastic Limit Test (g)
Mass of Tin B PL	Number	Mass of Tin B - Plastic Limit Test (g)

Figure 37 – Atterberg limits database table

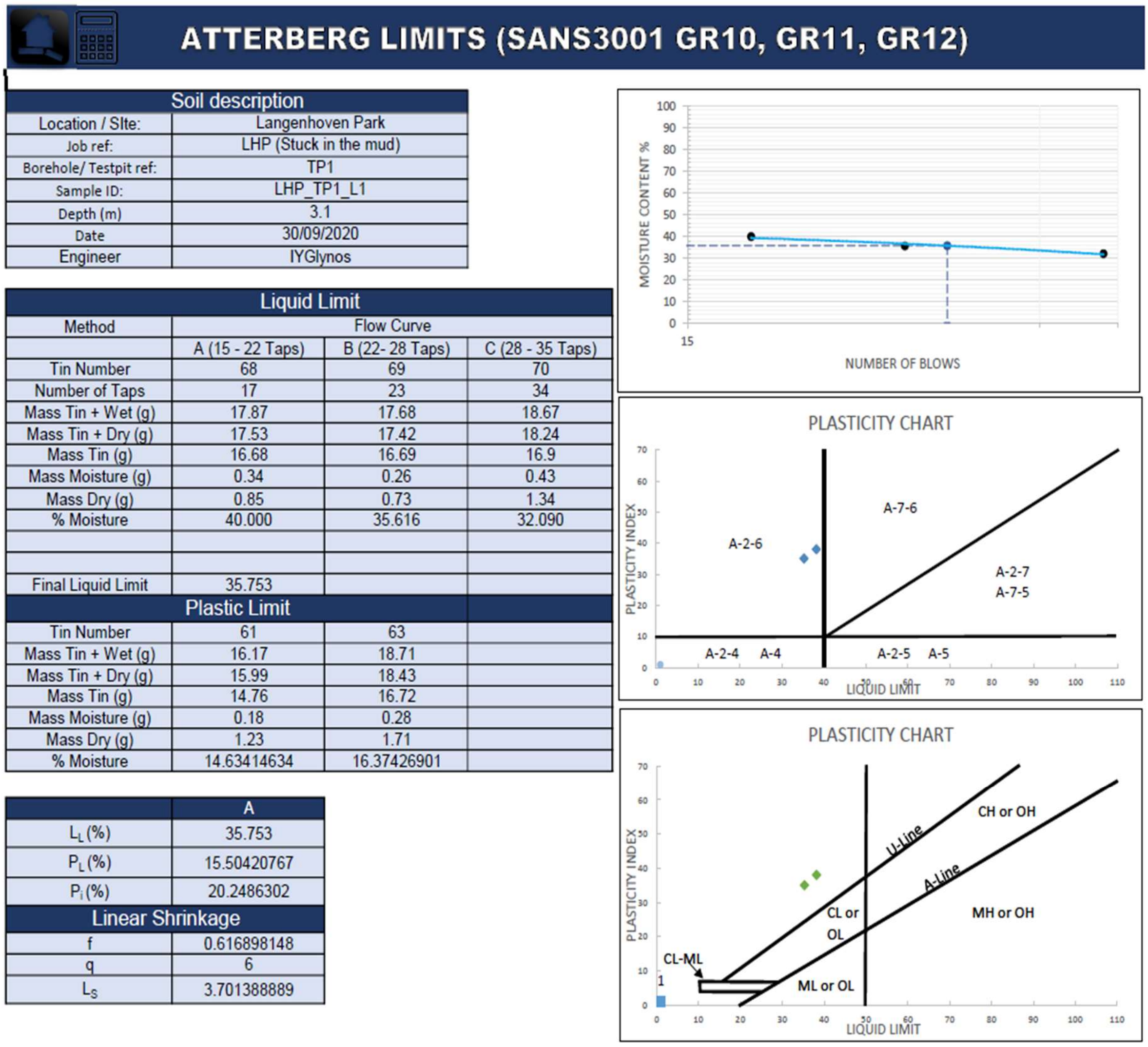
A separate table (Figure 38) was made for the linear shrinkage even though it is part of the Atterberg limits. This allowed every Atterberg limit test to have multiple linear shrinkage readings. This simplifies and optimises the database.



Field Name	Data Type	Description (Optional)
Linear Shrinkage ID	Short Text	Identity number used to identify the linear shrinkage
LL Test ID	Short Text	Primary Key used to Identify individual test performed
Date of Test	Date/Time	The date the Linear Shrinkage test was performed
Shrinkage	Number	The shrinkage (mm)
f	Number	Factor based on the number of taps

Figure 38 – Linear shrinkage database table

A query was made to call up data from both of these tables and the sample data table, which was then linked to the Atterberg limits worksheet. This allows all three tests for liquid limit and two tests for the plastic limit to be calculated, as well as linear shrinkage. As described in Chapter 2 for soil classification (as required outputs) three graphs were also shown with the information plotted on these three graphs (shown on the worksheet in Figure 39).



ATTERBERG LIMITS (SANS3001 GR10, GR11, GR12)

Soil description	
Location / SIte:	Langenhoven Park
Job ref:	LHP (Stuck in the mud)
Borehole/ Testpit ref:	TP1
Sample ID:	LHP_TP1_L1
Depth (m)	3.1
Date	30/09/2020
Engineer	IYGlynos

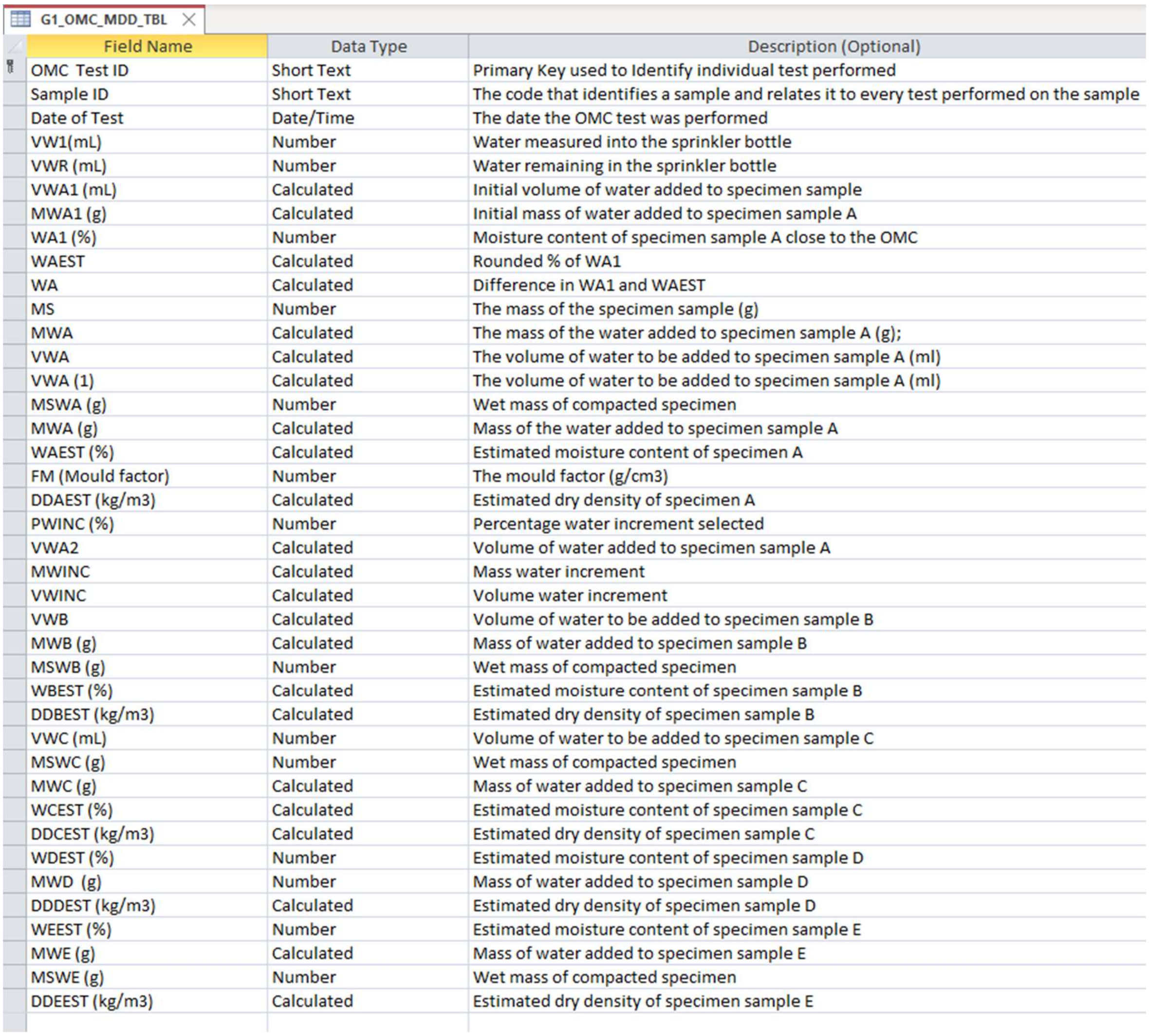
Liquid Limit			
Method	Flow Curve		
	A (15 - 22 Taps)	B (22- 28 Taps)	C (28 - 35 Taps)
Tin Number	68	69	70
Number of Taps	17	23	34
Mass Tin + Wet (g)	17.87	17.68	18.67
Mass Tin + Dry (g)	17.53	17.42	18.24
Mass Tin (g)	16.68	16.69	16.9
Mass Moisture (g)	0.34	0.26	0.43
Mass Dry (g)	0.85	0.73	1.34
% Moisture	40.000	35.616	32.090
Final Liquid Limit	35.753		
Plastic Limit			
Tin Number	61	63	
Mass Tin + Wet (g)	16.17	18.71	
Mass Tin + Dry (g)	15.99	18.43	
Mass Tin (g)	14.76	16.72	
Mass Moisture (g)	0.18	0.28	
Mass Dry (g)	1.23	1.71	
% Moisture	14.63414634	16.37426901	

	A
L_L (%)	35.753
P_L (%)	15.50420767
P_I (%)	20.2486302
Linear Shrinkage	
f	0.616898148
q	6
L_S	3.701388889

Figure 39 – Atterberg limits and linear shrinkage worksheet

4.4.6 Optimum moisture content and maximum dry density

The SANS3001 GR30 covers the optimum moisture content and maximum dry density test. A table (Figure 40) was created for storage of the values that determine these values. This table stores the input values, which were also transformed to get the intermediate values.

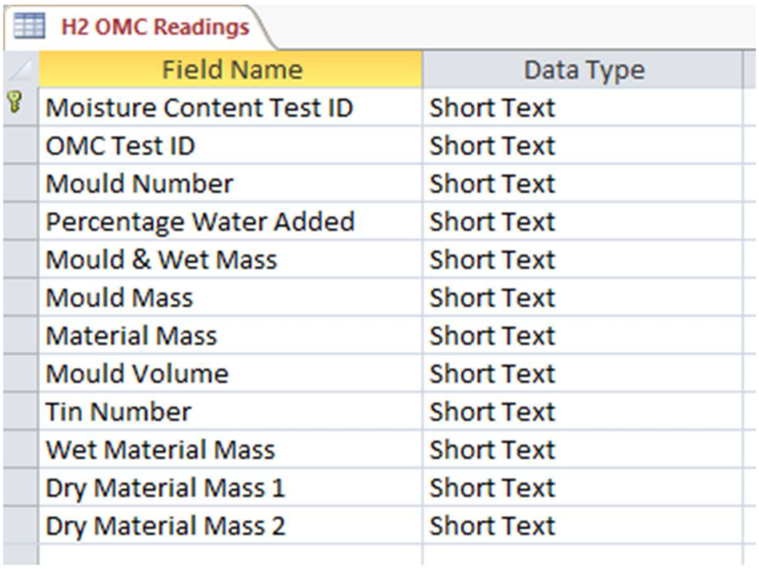


G1_OMC_MDD_TBL

Field Name	Data Type	Description (Optional)
OMC Test ID	Short Text	Primary Key used to Identify individual test performed
Sample ID	Short Text	The code that identifies a sample and relates it to every test performed on the sample
Date of Test	Date/Time	The date the OMC test was performed
VW1(mL)	Number	Water measured into the sprinkler bottle
VWR (mL)	Number	Water remaining in the sprinkler bottle
VWA1 (mL)	Calculated	Initial volume of water added to specimen sample
MWA1 (g)	Calculated	Initial mass of water added to specimen sample A
WA1 (%)	Number	Moisture content of specimen sample A close to the OMC
WAEST	Calculated	Rounded % of WA1
WA	Calculated	Difference in WA1 and WAEST
MS	Number	The mass of the specimen sample (g)
MWA	Calculated	The mass of the water added to specimen sample A (g);
VWA	Calculated	The volume of water to be added to specimen sample A (ml)
VWA (1)	Calculated	The volume of water to be added to specimen sample A (ml)
MSWA (g)	Number	Wet mass of compacted specimen
MWA (g)	Calculated	Mass of the water added to specimen sample A
WAEST (%)	Calculated	Estimated moisture content of specimen A
FM (Mould factor)	Number	The mould factor (g/cm3)
DDAEST (kg/m3)	Calculated	Estimated dry density of specimen A
PWINC (%)	Number	Percentage water increment selected
VWA2	Calculated	Volume of water added to specimen sample A
MWINC	Calculated	Mass water increment
VWINC	Calculated	Volume water increment
VWB	Calculated	Volume of water to be added to specimen sample B
MWB (g)	Calculated	Mass of water added to specimen sample B
MSWB (g)	Number	Wet mass of compacted specimen
WBEST (%)	Calculated	Estimated moisture content of specimen sample B
DDBEST (kg/m3)	Calculated	Estimated dry density of specimen sample B
VWC (mL)	Number	Volume of water to be added to specimen sample C
MSWC (g)	Number	Wet mass of compacted specimen
MWC (g)	Calculated	Mass of water added to specimen sample C
WCEST (%)	Calculated	Estimated moisture content of specimen sample C
DDCEST (kg/m3)	Calculated	Estimated dry density of specimen sample C
WDEST (%)	Number	Estimated moisture content of specimen sample D
MWD (g)	Number	Mass of water added to specimen sample D
DDDEST (kg/m3)	Calculated	Estimated dry density of specimen sample D
WEEST (%)	Number	Estimated moisture content of specimen sample E
MWE (g)	Calculated	Mass of water added to specimen sample E
MSWE (g)	Number	Wet mass of compacted specimen
DDEEST (kg/m3)	Calculated	Estimated dry density of specimen sample E

Figure 40 – OMC and MDD content database table

An additional table (Figure 41) was made for this test due to each test having multiple readings. Usually, five moulds are made during the test, but this allowed the test to have many moulds and optimise the table.

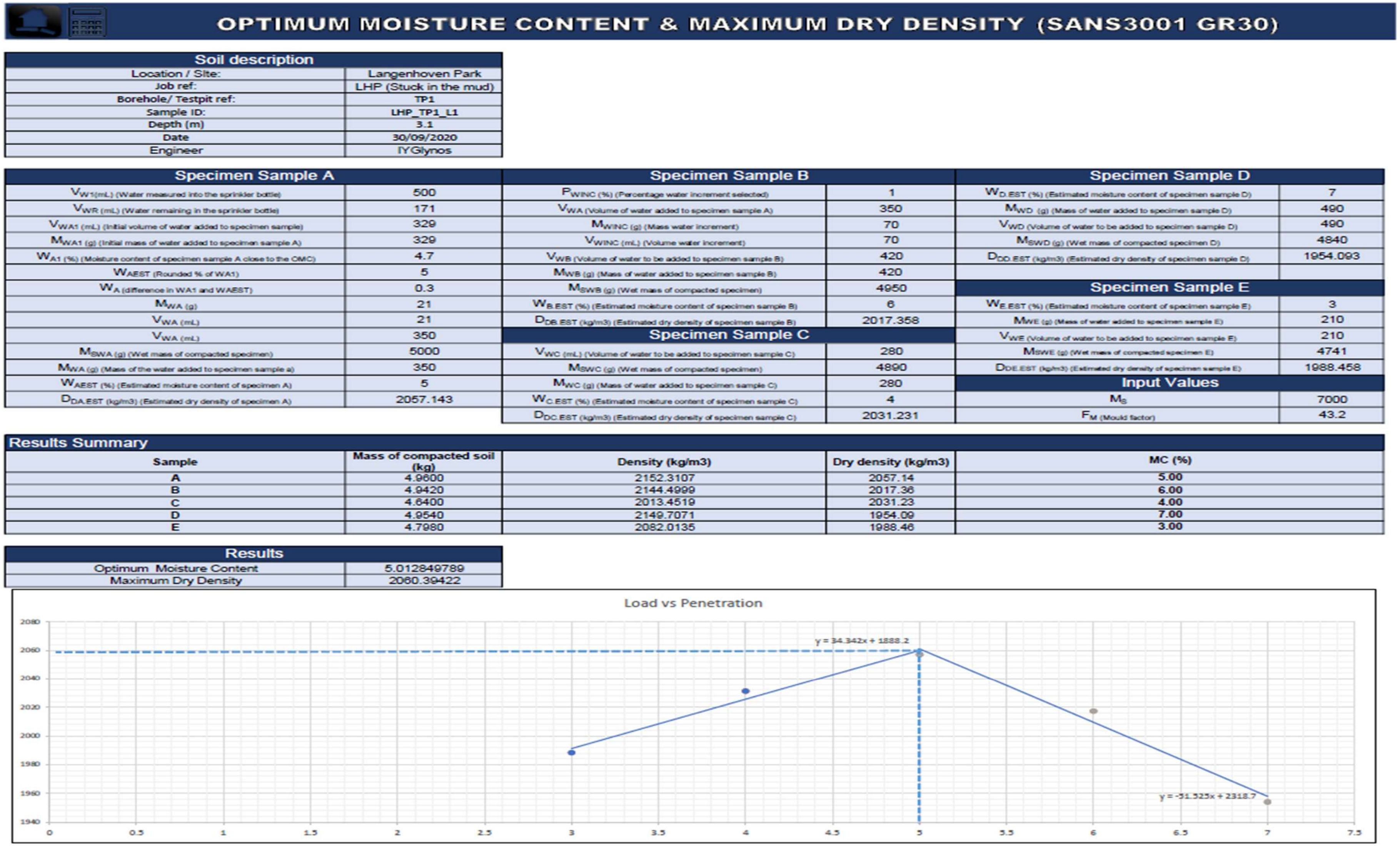


H2 OMC Readings

	Field Name	Data Type
🔑	Moisture Content Test ID	Short Text
	OMC Test ID	Short Text
	Mould Number	Short Text
	Percentage Water Added	Short Text
	Mould & Wet Mass	Short Text
	Mould Mass	Short Text
	Material Mass	Short Text
	Mould Volume	Short Text
	Tin Number	Short Text
	Wet Material Mass	Short Text
	Dry Material Mass 1	Short Text
	Dry Material Mass 2	Short Text

Figure 41 – OMC readings database table

The final values were calculated through the user interface on Microsoft Excel (Figure 42) due to the complex charting and calculations where Microsoft Access was inefficient.



OPTIMUM MOISTURE CONTENT & MAXIMUM DRY DENSITY (SANS3001 GR30)

Soil description	
Location / Site:	Langenhoven Park
Job ref:	LHP (Stuck in the mud)
Borehole/ Testpit ref:	TP1
Sample ID:	LHP_TP1_L1
Depth (m)	3.1
Date	30/09/2020
Engineer	IYGlynos

Specimen Sample A	
V_{W1} (mL) (Water measured into the sprinkler bottle)	500
V_{WR} (mL) (Water remaining in the sprinkler bottle)	171
V_{WA1} (mL) (Initial volume of water added to specimen sample)	329
M_{WA1} (g) (Initial mass of water added to specimen sample A)	329
W_{A1} (%) (Moisture content of specimen sample A close to the OMC)	4.7
W_{AEST} (Rounded % of WA1)	5
W_A (difference in WA1 and WAEST)	0.3
M_{WA} (g)	21
V_{WA} (mL)	21
V_{WA} (mL)	350
M_{SWA} (g) (Wet mass of compacted specimen)	5000
M_{WA} (g) (Mass of the water added to specimen sample a)	350
W_{AEST} (%) (Estimated moisture content of specimen A)	5
$D_{DA.EST}$ (kg/m3) (Estimated dry density of specimen A)	2057.143

Specimen Sample B	
P_{WINC} (%) (Percentage water increment selected)	1
V_{WA} (Volume of water added to specimen sample A)	350
M_{WINC} (g) (Mass water increment)	70
V_{WINC} (mL) (Volume water increment)	70
V_{WB} (Volume of water to be added to specimen sample B)	420
M_{WB} (g) (Mass of water added to specimen sample B)	420
M_{SWB} (g) (Wet mass of compacted specimen)	4950
$W_{B.EST}$ (%) (Estimated moisture content of specimen sample B)	6
$D_{DB.EST}$ (kg/m3) (Estimated dry density of specimen sample B)	2017.358

Specimen Sample C	
V_{WC} (mL) (Volume of water to be added to specimen sample C)	280
M_{SWC} (g) (Wet mass of compacted specimen)	4890
M_{WC} (g) (Mass of water added to specimen sample C)	280
$W_{C.EST}$ (%) (Estimated moisture content of specimen sample C)	4
$D_{DC.EST}$ (kg/m3) (Estimated dry density of specimen sample C)	2031.231

Specimen Sample D	
$W_{D.EST}$ (%) (Estimated moisture content of specimen sample D)	7
M_{WD} (g) (Mass of water added to specimen sample D)	490
V_{WD} (Volume of water to be added to specimen sample D)	490
M_{SWD} (g) (Wet mass of compacted specimen D)	4840
$D_{DD.EST}$ (kg/m3) (Estimated dry density of specimen sample D)	1954.093

Specimen Sample E	
$W_{E.EST}$ (%) (Estimated moisture content of specimen sample E)	3
M_{WE} (g) (Mass of water added to specimen sample E)	210
V_{WE} (Volume of water to be added to specimen sample E)	210
M_{SWE} (g) (Wet mass of compacted specimen E)	4741
$D_{DE.EST}$ (kg/m3) (Estimated dry density of specimen sample E)	1988.458

Input Values	
M_S	7000
F_M (Mould factor)	43.2

Results Summary

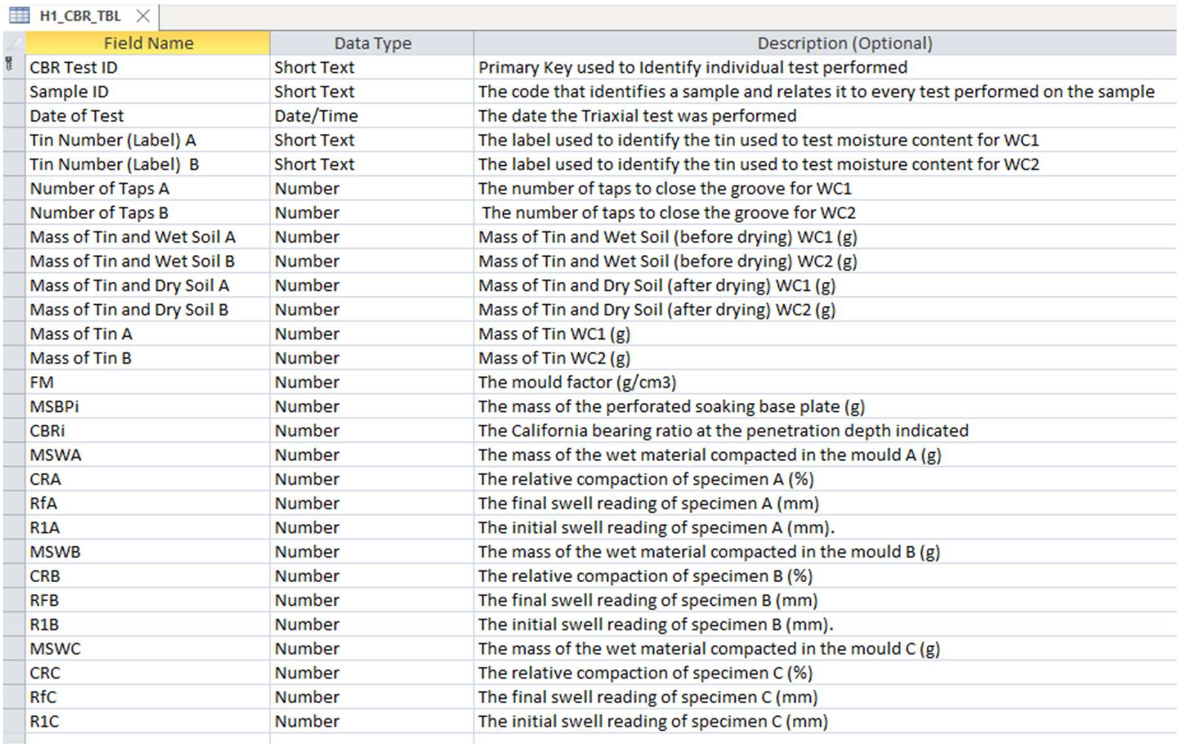
Sample	Mass of compacted soil (kg)	Density (kg/m3)	Dry density (kg/m3)	MC (%)
A	4.9600	2152.3107	2057.14	5.00
B	4.9420	2144.4999	2017.36	6.00
C	4.6400	2013.4519	2031.23	4.00
D	4.9540	2149.7071	1954.09	7.00
E	4.7980	2082.0135	1988.46	3.00

Results	
Optimum Moisture Content	5.012849789
Maximum Dry Density	2060.39422

Figure 42 - OMC and MDD worksheet

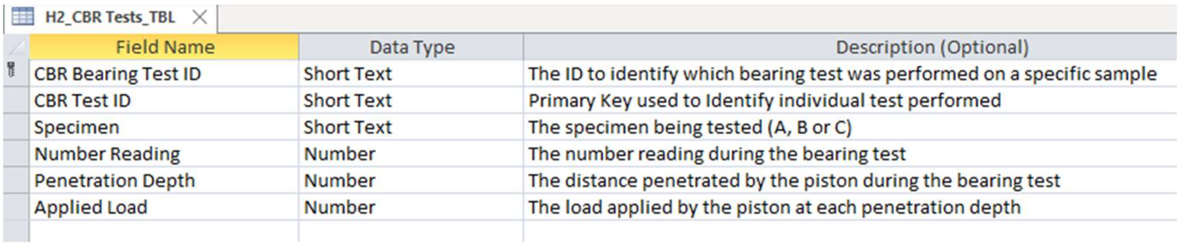
4.4.7 California bearing ratio

A table (Figure 43) for the California bearing ratio (CBR) test described in the SANS3001 GR40 was created with an additional table as with the optimum moisture content and maximum dry density tables. The first table stores the test's important values for the test, while the second table records all the readings recorded during the penetration part of the test. The penetration phase could have many readings, making it inefficient to create multiple fields for each time readings; therefore, the second table (Figure 44) could have multiple records related to one CBR test.



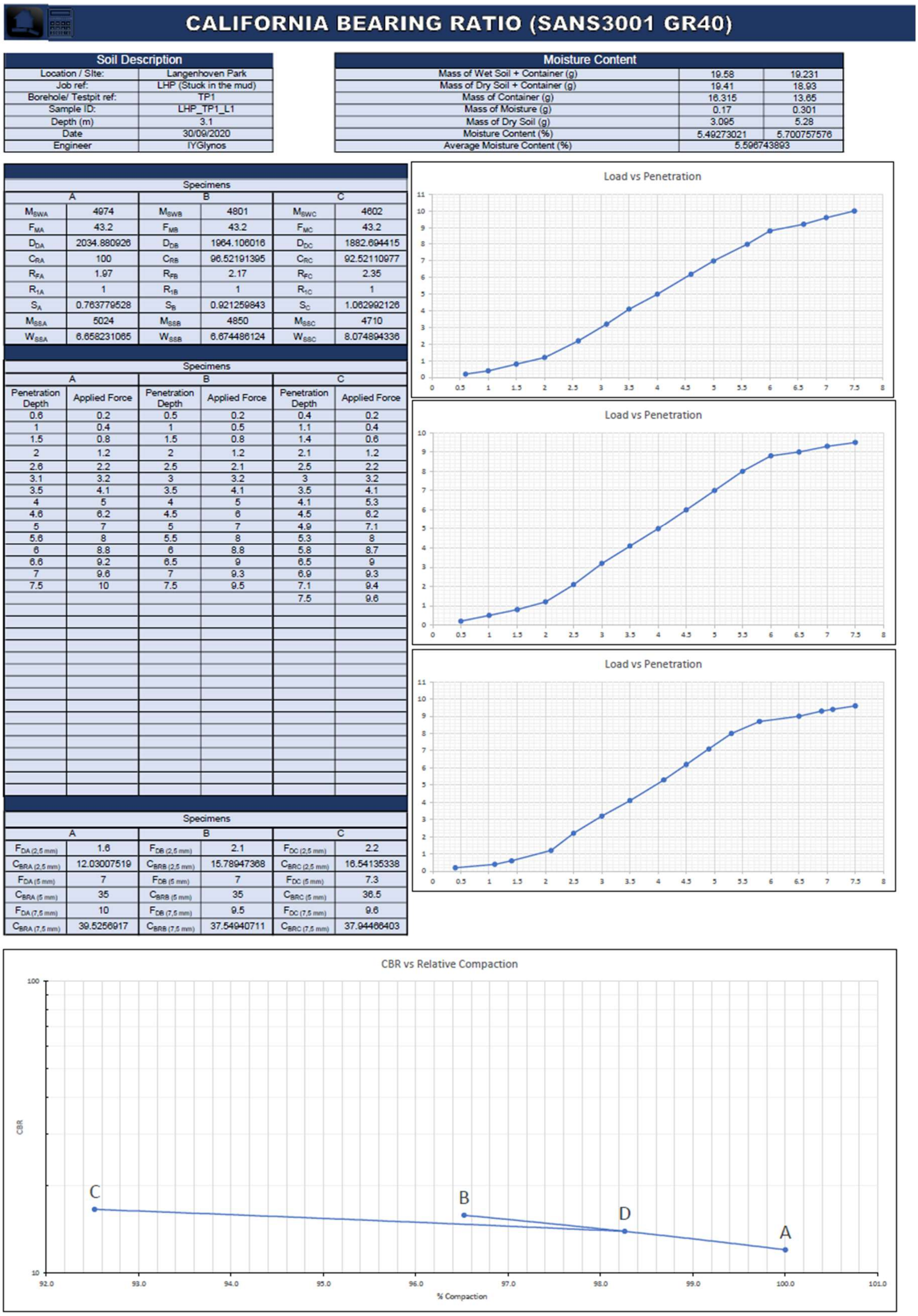
Field Name	Data Type	Description (Optional)
CBR Test ID	Short Text	Primary Key used to Identify individual test performed
Sample ID	Short Text	The code that identifies a sample and relates it to every test performed on the sample
Date of Test	Date/Time	The date the Triaxial test was performed
Tin Number (Label) A	Short Text	The label used to identify the tin used to test moisture content for WC1
Tin Number (Label) B	Short Text	The label used to identify the tin used to test moisture content for WC2
Number of Taps A	Number	The number of taps to close the groove for WC1
Number of Taps B	Number	The number of taps to close the groove for WC2
Mass of Tin and Wet Soil A	Number	Mass of Tin and Wet Soil (before drying) WC1 (g)
Mass of Tin and Wet Soil B	Number	Mass of Tin and Wet Soil (before drying) WC2 (g)
Mass of Tin and Dry Soil A	Number	Mass of Tin and Dry Soil (after drying) WC1 (g)
Mass of Tin and Dry Soil B	Number	Mass of Tin and Dry Soil (after drying) WC2 (g)
Mass of Tin A	Number	Mass of Tin WC1 (g)
Mass of Tin B	Number	Mass of Tin WC2 (g)
FM	Number	The mould factor (g/cm3)
MSBPi	Number	The mass of the perforated soaking base plate (g)
CBRi	Number	The California bearing ratio at the penetration depth indicated
MSWA	Number	The mass of the wet material compacted in the mould A (g)
CRA	Number	The relative compaction of specimen A (%)
RfA	Number	The final swell reading of specimen A (mm)
R1A	Number	The initial swell reading of specimen A (mm).
MSWB	Number	The mass of the wet material compacted in the mould B (g)
CRB	Number	The relative compaction of specimen B (%)
RFB	Number	The final swell reading of specimen B (mm)
R1B	Number	The initial swell reading of specimen B (mm).
MSWC	Number	The mass of the wet material compacted in the mould C (g)
CRC	Number	The relative compaction of specimen C (%)
RfC	Number	The final swell reading of specimen C (mm)
R1C	Number	The initial swell reading of specimen C (mm)

Figure 43 – California bearing ratio database table



Field Name	Data Type	Description (Optional)
CBR Bearing Test ID	Short Text	The ID to identify which bearing test was performed on a specific sample
CBR Test ID	Short Text	Primary Key used to Identify individual test performed
Specimen	Short Text	The specimen being tested (A, B or C)
Number Reading	Number	The number reading during the bearing test
Penetration Depth	Number	The distance penetrated by the piston during the bearing test
Applied Load	Number	The load applied by the piston at each penetration depth

Figure 44 - California bearing ratio tests database table



CALIFORNIA BEARING RATIO (SANS3001 GR40)

Soil Description

Location / Site:	Langenhoven Park
Job ref:	LHP (Stuck in the mud)
Borehole/ Testpit ref:	TP1
Sample ID:	LHP_TP1_L1
Depth (m)	3.1
Date	30/09/2020
Engineer	IYGlynos

Moisture Content

Mass of Wet Soil + Container (g)	19.58	19.231
Mass of Dry Soil + Container (g)	19.41	18.93
Mass of Container (g)	16.315	13.65
Mass of Moisture (g)	0.17	0.301
Mass of Dry Soil (g)	3.095	5.28
Moisture Content (%)	5.49273021	5.700757576
Average Moisture Content (%)	5.596743893	

Specimens

A		B		C	
M_{SWA}	4974	M_{SWB}	4801	M_{SWC}	4602
F_{MA}	43.2	F_{MB}	43.2	F_{MC}	43.2
D_{DA}	2034.880926	D_{DB}	1964.106016	D_{DC}	1882.694415
C_{RA}	100	C_{RB}	96.52191395	C_{RC}	92.52110977
R_{FA}	1.97	R_{FB}	2.17	R_{FC}	2.35
R_{1A}	1	R_{1B}	1	R_{1C}	1
S_A	0.763779528	S_B	0.921259843	S_C	1.062992126
M_{SSA}	5024	M_{SSB}	4850	M_{SSC}	4710
W_{SSA}	6.658231065	W_{SSB}	6.674486124	W_{SSC}	8.074894336

Specimens

A		B		C	
Penetration Depth	Applied Force	Penetration Depth	Applied Force	Penetration Depth	Applied Force
0.6	0.2	0.5	0.2	0.4	0.2
1	0.4	1	0.5	1.1	0.4
1.5	0.8	1.5	0.8	1.4	0.6
2	1.2	2	1.2	2.1	1.2
2.6	2.2	2.5	2.1	2.5	2.2
3.1	3.2	3	3.2	3	3.2
3.5	4.1	3.5	4.1	3.5	4.1
4	5	4	5	4.1	5.3
4.6	6.2	4.5	6	4.5	6.2
5	7	5	7	4.9	7.1
5.6	8	5.5	8	5.3	8
6	8.8	6	8.8	5.8	8.7
6.6	9.2	6.5	9	6.5	9
7	9.6	7	9.3	6.9	9.3
7.5	10	7.5	9.5	7.1	9.4
				7.5	9.6

Specimens

A		B		C	
$F_{DA\ (2,5\ mm)}$	1.6	$F_{DB\ (2,5\ mm)}$	2.1	$F_{DC\ (2,5\ mm)}$	2.2
$C_{BRA\ (2,5\ mm)}$	12.03007519	$C_{BRB\ (2,5\ mm)}$	15.78947368	$C_{BRC\ (2,5\ mm)}$	16.54135338
$F_{DA\ (5\ mm)}$	7	$F_{DB\ (5\ mm)}$	7	$F_{DC\ (5\ mm)}$	7.3
$C_{BRA\ (5\ mm)}$	35	$C_{BRB\ (5\ mm)}$	35	$C_{BRC\ (5\ mm)}$	36.5
$F_{DA\ (7,5\ mm)}$	10	$F_{DB\ (7,5\ mm)}$	9.5	$F_{DC\ (7,5\ mm)}$	9.6
$C_{BRA\ (7,5\ mm)}$	39.5256917	$C_{BRB\ (7,5\ mm)}$	37.54940711	$C_{BRC\ (7,5\ mm)}$	37.94466403

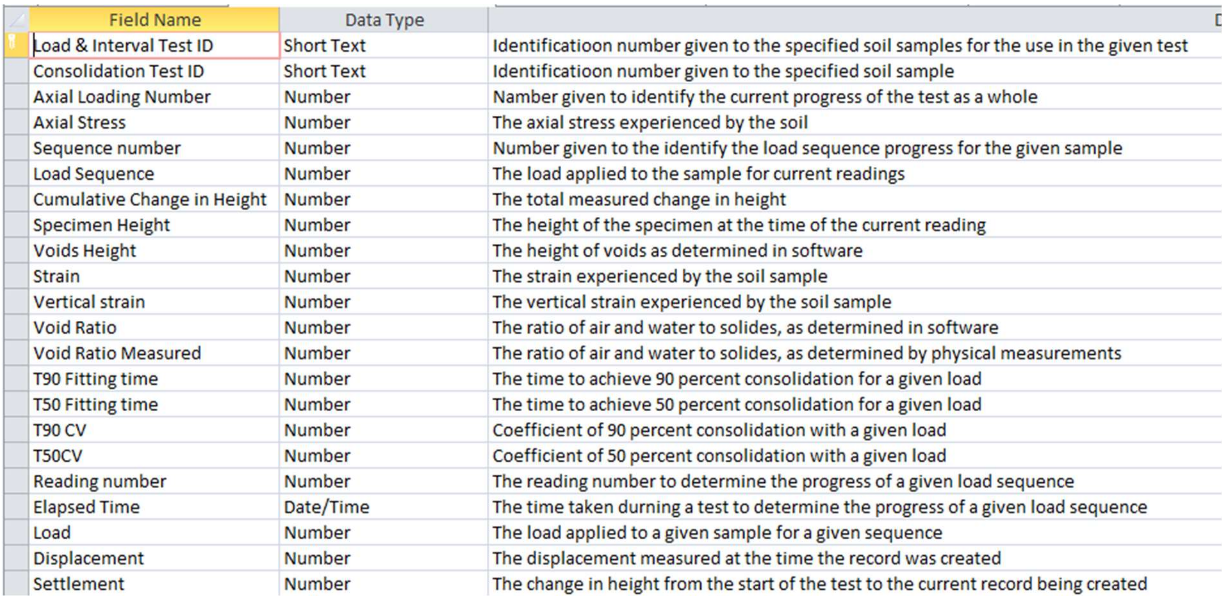
Figure 45 – California bearing ratio worksheet

4.4.8 One-dimensional consolidation

The consolidation test tables also used two tables as there were multiple readings for the depth first-time readings. The first table allows the user to enter information about the test itself, including all key inputs. Consolidation values were, therefore, described in the first table, and the actual stress and time heights were described in the second table.

Field Name	Data Type	D
Consolidation Test ID	Short Text	Primary Key used to Identify individual test performed
Sample Id	Short Text	Identification number given to the specified soil sample
Date of Test	Date/Time	The date the test was started
Specific Gravity	Number	The specific gravity of the sample soil, as measured
Initial Specimen Diameter	Number	The measured diameter of the soil sample before the test is done
Initial Specimen Area	Calculated	The calculated top down area of the sample, based off the measured sample diameter
Final Specimen Diameter	Number	The measured diameter of the soil sample after the test is completed
Final Specimen Area	Calculated	The calculated top down area of the sample, based off the measured sample diameter
Initial Specimen Height	Number	The height of the specimen as measured before the test is done
Initial Specimen Volume	Calculated	The volume of the specimen as calculated off the height and diameter
Final Specimen Height	Number	The height of the specimen as measured after the test is completed
Final Specimen Volume	Calculated	The volume of the specimen as calculated off the height and diameter
Initial Tin Number	Number	The identification number of the moisture content tin
Initial Wet & Dry Soil in Ring W	Number	Combined weight of the soil and trim ring
Initial Dry Soil & Ring Weight	Number	Combined weight of the dry soil and trim ring
Initial Trim Ring Weight	Number	Weight of the trim ring only
Wet Soil Weight (Initial)	Calculated	Weight of the wet soil only, calculated by subtracting ring weight from wet soil and ring
Dry Soil Weight (Initial)	Calculated	Weight of the dry soil only, calculated by subtracting ring weight from dry soil and ring
Initial Moisture Content	Calculated	Moisture content of sample before testing is done
Final Moisture Content	Calculated	Moisture content of sample after test is completed
Seating Load	Number	The pressure applied to the sample prior to the test begining
Final Wet & Dry Soil in Ring We	Number	Combined weight of the soil and trim ring after the test is completed
Final Dry Soil & Ring Weight	Number	Combined weight of the dry soil and trim ring after the test is completed
Final Trim Ring Weight	Number	Weight of the trim ring only
Wet Soil Weight (Final)	Calculated	Weight of the wet soil only, calculated by subtracting ring weight from wet soil and ring
Dry Soil Weight (Final)	Calculated	Weight of the dry soil only, calculated by subtracting ring weight from dry soil and ring
Initial Moisture content (from	Number	Moisture content of sample before testing is done, acquired by collecting trimmings
Final Moisture content (from t	Number	Moisture content of sample after test is completed, acquired by collecting trimmings
Initial Mass (g)	Number	Weight of the sample before testing is done
Final Mass (g)	Number	Weight of the sample after testing has been completed
Initial Bulk Density	Calculated	Density of soil expressed as kg/m^3 before test is done
Final Bulk Density	Calculated	Density of soil expressed as kg/m^3 after test is completed
Initial Density	Calculated	Density of soil expressed as kg/m^3 before test is done

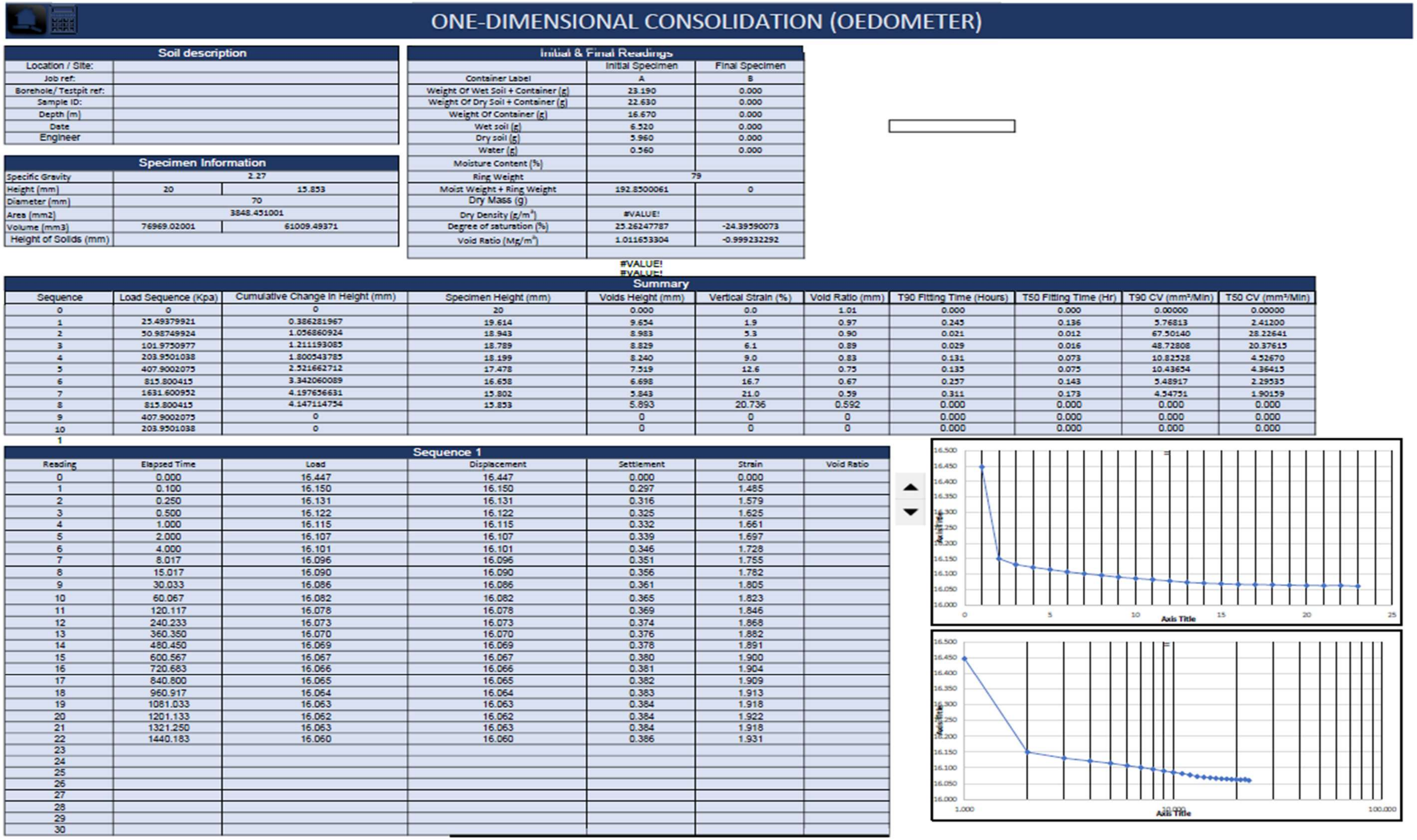
Figure 46 - Consolidation database table



Field Name	Data Type	D
Load & Interval Test ID	Short Text	Identificatioon number given to the specified soil samples for the use in the given test
Consolidation Test ID	Short Text	Identificatioon number given to the specified soil sample
Axial Loading Number	Number	Namber given to identify the current progress of the test as a whole
Axial Stress	Number	The axial stress experienced by the soil
Sequence number	Number	Number given to the identify the load sequence progress for the given sample
Load Sequence	Number	The load applied to the sample for current readings
Cumulative Change in Height	Number	The total measured change in height
Specimen Height	Number	The height of the specimen at the time of the current reading
Voids Height	Number	The height of voids as determined in software
Strain	Number	The strain experienced by the soil sample
Vertical strain	Number	The vertical strain experienced by the soil sample
Void Ratio	Number	The ratio of air and water to solides, as determined in software
Void Ratio Measured	Number	The ratio of air and water to solides, as determined by physical measurements
T90 Fitting time	Number	The time to achieve 90 percent consolidation for a given load
T50 Fitting time	Number	The time to achieve 50 percent consolidation for a given load
T90 CV	Number	Coefficient of 90 percent consolidation with a given load
T50CV	Number	Coefficient of 50 percent consolidation with a given load
Reading number	Number	The reading number to determine the progress of a given load sequence
Elapsed Time	Date/Time	The time taken durning a test to determine the progress of a given load sequence
Load	Number	The load applied to a given sample for a given sequence
Displacement	Number	The displacement measured at the time the record was created
Settlement	Number	The change in height from the start of the test to the current record being created

Figure 47 – Axial stress time heights database table

The final values and charting were calculated through the user interface on Microsoft Excel (Figure 48) due to the complex charting and calculations where Microsoft Access was inefficient.



ONE-DIMENSIONAL CONSOLIDATION (OEDOMETER)

Soil description

Location / Site:	
Job ref:	
Borehole/ Testpit ref:	
Sample ID:	
Depth (m)	
Date	
Engineer	

Specimen Information

Specific Gravity	2.27	
Height (mm)	20	15.853
Diameter (mm)	70	
Area (mm2)	3848.451001	
Volume (mm3)	76969.02001	61009.49371
Height of Solids (mm)		

Initial & Final Readings

	Initial Specimen	Final Specimen
Container Label	A	B
Weight Of Wet Soil + Container (g)	23.190	0.000
Weight Of Dry Soil + Container (g)	22.630	0.000
Weight Of Container (g)	16.670	0.000
Wet soil (g)	6.520	0.000
Dry soil (g)	5.960	0.000
Water (g)	0.560	0.000
Moisture Content (%)		
Ring Weight	79	
Moist Weight + Ring Weight	192.8500061	0
Dry Mass (g)		
Dry Density (g/m³)	#VALUE!	
Degree of saturation (%)	25.26247787	-24.39590073
Void Ratio (Mg/m³)	1.011653304	-0.999232292

#VALUE!
#VALUE!

Summary

Sequence	Load Sequence (Kpa)	Cumulative Change In Height (mm)	Specimen Height (mm)	Voids Height (mm)	Vertical Strain (%)	Void Ratio (mm)	T90 Fitting Time (Hours)	T50 Fitting Time (Hr)	T90 CV (mm²/Min)	T50 CV (mm²/Min)
0	0	0	20	0.000	0.0	1.01	0.000	0.000	0.00000	0.00000
1	25.49379921	0.386281967	19.614	9.654	1.9	0.97	0.245	0.136	5.76813	2.41200
2	50.98749924	1.056860924	18.943	8.983	5.3	0.90	0.021	0.012	67.50140	28.22641
3	101.9750977	1.211193085	18.789	8.829	6.1	0.89	0.029	0.016	48.72808	20.37615
4	203.9501038	1.800543785	18.199	8.240	9.0	0.83	0.131	0.073	10.82528	4.52670
5	407.9002075	2.521662712	17.478	7.519	12.6	0.75	0.135	0.075	10.43654	4.36415
6	815.800415	3.342060089	16.658	6.698	16.7	0.67	0.257	0.143	5.48917	2.29535
7	1631.600952	4.197656631	15.802	5.843	21.0	0.59	0.311	0.173	4.54751	1.90159
8	815.800415	4.147114754	15.853	5.893	20.736	0.592	0.000	0.000	0.000	0.000
9	407.9002075	0		0	0	0	0.000	0.000	0.000	0.000
10	203.9501038	0		0	0	0	0.000	0.000	0.000	0.000

1

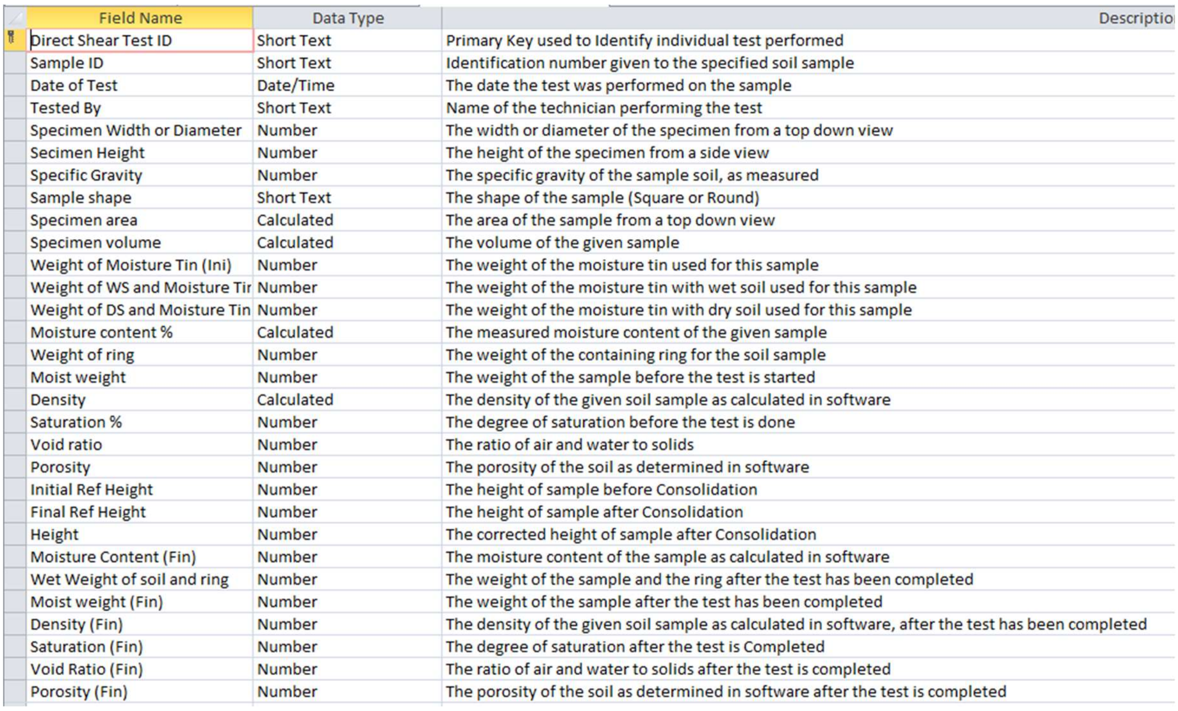
Sequence 1

Reading	Elapsed Time	Load	Displacement	Settlement	Strain	Void Ratio
0	0.000	16.447	16.447	0.000	0.000	
1	0.100	16.150	16.150	0.297	1.485	
2	0.250	16.131	16.131	0.316	1.579	
3	0.500	16.122	16.122	0.325	1.625	
4	1.000	16.115	16.115	0.332	1.661	
5	2.000	16.107	16.107	0.339	1.697	
6	4.000	16.101	16.101	0.346	1.728	
7	8.017	16.096	16.096	0.351	1.755	
8	15.017	16.090	16.090	0.356	1.782	
9	30.033	16.086	16.086	0.361	1.805	
10	60.067	16.082	16.082	0.365	1.823	
11	120.117	16.078	16.078	0.369	1.846	
12	240.233	16.073	16.073	0.374	1.868	
13	360.350	16.070	16.070	0.376	1.882	
14	480.450	16.069	16.069	0.378	1.891	
15	600.567	16.067	16.067	0.380	1.900	
16	720.683	16.066	16.066	0.381	1.904	
17	840.800	16.065	16.065	0.382	1.909	
18	960.917	16.064	16.064	0.383	1.913	
19	1081.033	16.063	16.063	0.384	1.918	
20	1201.133	16.062	16.062	0.384	1.922	
21	1321.250	16.063	16.063	0.384	1.918	
22	1440.183	16.060	16.060	0.386	1.931	
23						
24						
25						
26						
27						
28						
29						
30						

Figure 48 - One-dimensional consolidation worksheet

4.4.9 Direct Shear

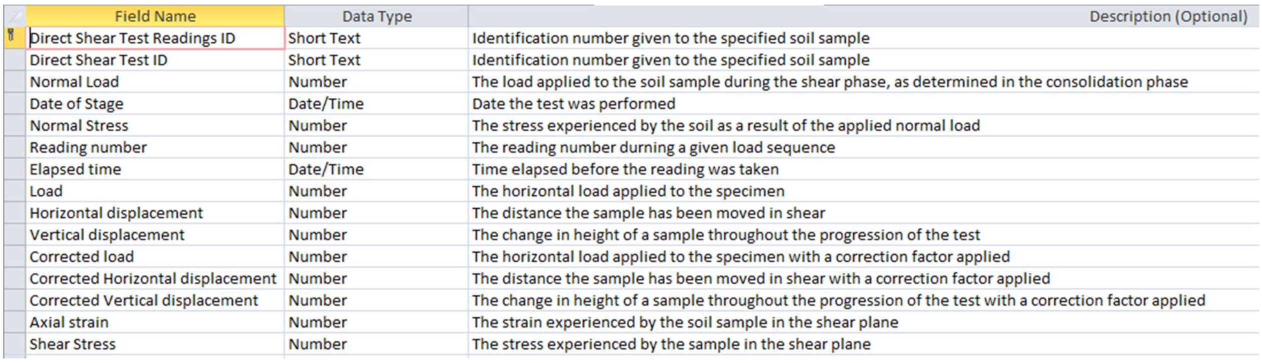
The direct shear test tables make use of two tables as there were multiple readings for the stress and displacement readings. The first table (Figure 49) allows the user to enter information about the test itself, including all key inputs



Field Name	Data Type	Descriptio
Direct Shear Test ID	Short Text	Primary Key used to Identify individual test performed
Sample ID	Short Text	Identification number given to the specified soil sample
Date of Test	Date/Time	The date the test was performed on the sample
Tested By	Short Text	Name of the technician performing the test
Specimen Width or Diameter	Number	The width or diameter of the specimen from a top down view
Secimen Height	Number	The height of the specimen from a side view
Specific Gravity	Number	The specific gravity of the sample soil, as measured
Sample shape	Short Text	The shape of the sample (Square or Round)
Specimen area	Calculated	The area of the sample from a top down view
Specimen volume	Calculated	The volume of the given sample
Weight of Moisture Tin (Ini)	Number	The weight of the moisture tin used for this sample
Weight of WS and Moisture Tir	Number	The weight of the moisture tin with wet soil used for this sample
Weight of DS and Moisture Tin	Number	The weight of the moisture tin with dry soil used for this sample
Moisture content %	Calculated	The measured moisture content of the given sample
Weight of ring	Number	The weight of the containing ring for the soil sample
Moist weight	Number	The weight of the sample before the test is started
Density	Calculated	The density of the given soil sample as calculated in software
Saturation %	Number	The degree of saturation before the test is done
Void ratio	Number	The ratio of air and water to solids
Porosity	Number	The porosity of the soil as determined in software
Initial Ref Height	Number	The height of sample before Consolidation
Final Ref Height	Number	The height of sample after Consolidation
Height	Number	The corrected height of sample after Consolidation
Moisture Content (Fin)	Number	The moisture content of the sample as calculated in software
Wet Weight of soil and ring	Number	The weight of the sample and the ring after the test has been completed
Moist weight (Fin)	Number	The weight of the sample after the test has been completed
Density (Fin)	Number	The density of the given soil sample as calculated in software, after the test has been completed
Saturation (Fin)	Number	The degree of saturation after the test is Completed
Void Ratio (Fin)	Number	The ratio of air and water to solids after the test is completed
Porosity (Fin)	Number	The porosity of the soil as determined in software after the test is completed

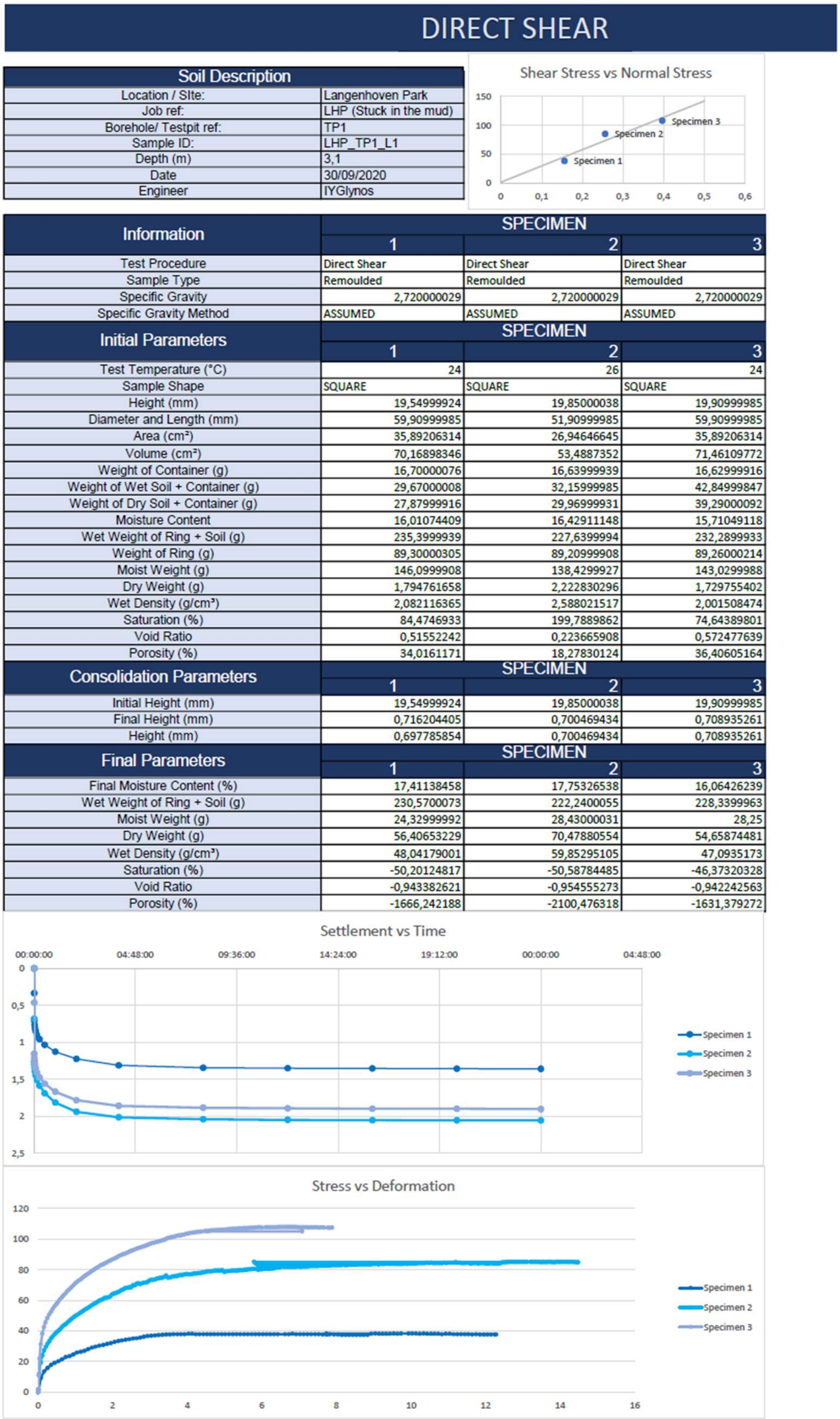
Figure 49 – Direct shear database table

The second table (Figure 50) stores all the from the shear phase of the test.



Field Name	Data Type	Description (Optional)
Direct Shear Test Readings ID	Short Text	Identification number given to the specified soil sample
Direct Shear Test ID	Short Text	Identification number given to the specified soil sample
Normal Load	Number	The load applied to the soil sample during the shear phase, as determined in the consolidation phase
Date of Stage	Date/Time	Date the test was performed
Normal Stress	Number	The stress experienced by the soil as a result of the applied normal load
Reading number	Number	The reading number durning a given load sequence
Elapsed time	Date/Time	Time elapsed before the reading was taken
Load	Number	The horizontal load applied to the specimen
Horizontal displacement	Number	The distance the sample has been moved in shear
Vertical displacement	Number	The change in height of a sample throughout the progression of the test
Corrected load	Number	The horizontal load applied to the specimen with a correction factor applied
Corrected Horizontal displacement	Number	The distance the sample has been moved in shear with a correction factor applied
Corrected Vertical displacement	Number	The change in height of a sample throughout the progression of the test with a correction factor applied
Axial strain	Number	The strain experienced by the soil sample in the shear plane
Shear Stress	Number	The stress experienced by the sample in the shear plane

Figure 50 – Stress and displacement database table



DIRECT SHEAR

Soil Description	
Location / SIte:	Langenhoven Park
Job ref:	LHP (Stuck in the mud)
Borehole/ Testpit ref:	TP1
Sample ID:	LHP_TP1_L1
Depth (m)	3,1
Date	30/09/2020
Engineer	IYGlynos

Information	SPECIMEN		
	1	2	3
Test Procedure	Direct Shear	Direct Shear	Direct Shear
Sample Type	Remoulded	Remoulded	Remoulded
Specific Gravity	2,720000029	2,720000029	2,720000029
Specific Gravity Method	ASSUMED	ASSUMED	ASSUMED

Initial Parameters	SPECIMEN		
	1	2	3
Test Temperature (°C)	24	26	24
Sample Shape	SQUARE	SQUARE	SQUARE
Height (mm)	19,54999924	19,85000038	19,90999985
Diameter and Length (mm)	59,90999985	51,90999985	59,90999985
Area (cm²)	35,89206314	26,94646645	35,89206314
Volume (cm³)	70,16898346	53,4887352	71,46109772
Weight of Container (g)	16,70000076	16,63999939	16,62999916
Weight of Wet Soil + Container (g)	29,67000008	32,15999985	42,84999847
Weight of Dry Soil + Container (g)	27,87999916	29,96999931	39,29000092
Moisture Content	16,01074409	16,42911148	15,71049118
Wet Weight of Ring + Soil (g)	235,3999939	227,6399994	232,2899933
Weight of Ring (g)	89,30000305	89,20999908	89,26000214
Moist Weight (g)	146,0999908	138,4299927	143,0299988
Dry Weight (g)	1,794761658	2,222830296	1,729755402
Wet Density (g/cm³)	2,082116365	2,588021517	2,001508474
Saturation (%)	84,4746933	199,7889862	74,64389801
Void Ratio	0,51552242	0,223665908	0,572477639
Porosity (%)	34,0161171	18,27830124	36,40605164

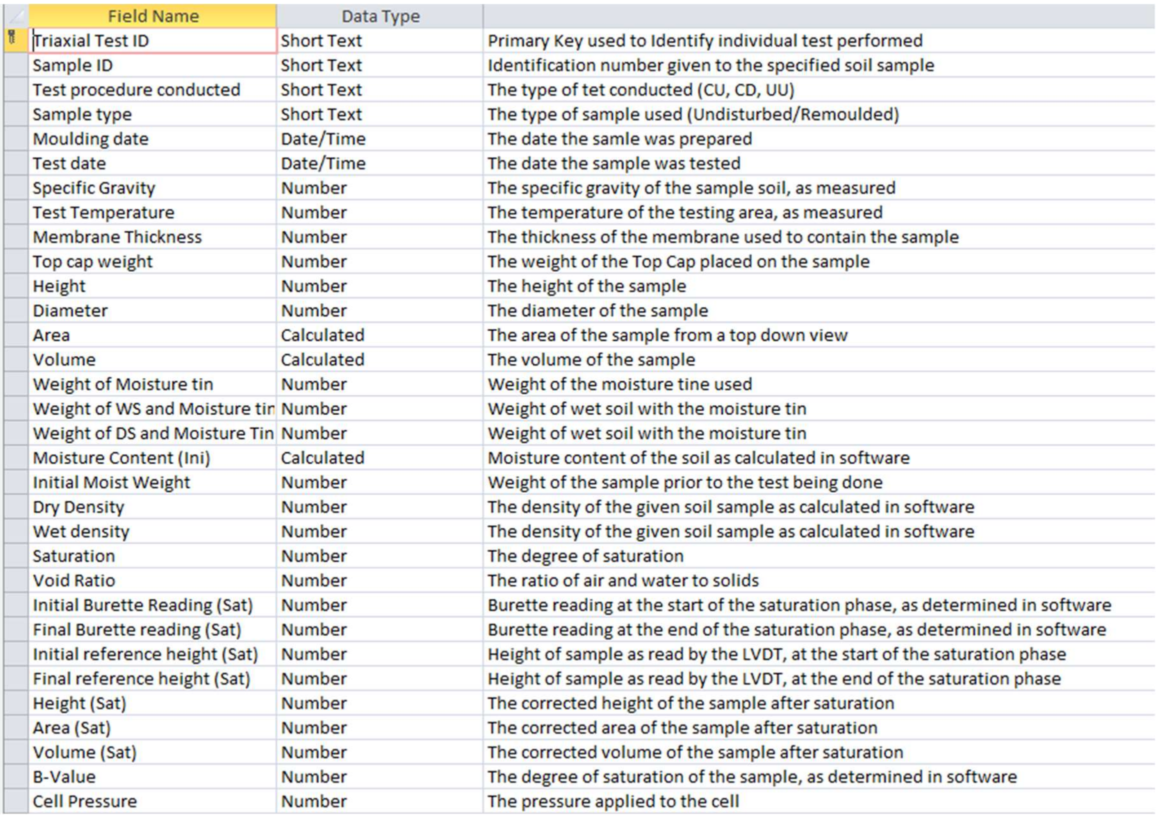
Consolidation Parameters	SPECIMEN		
	1	2	3
Initial Height (mm)	19,54999924	19,85000038	19,90999985
Final Height (mm)	0,716204405	0,700469434	0,708935261
Height (mm)	0,697785854	0,700469434	0,708935261

Final Parameters	SPECIMEN		
	1	2	3
Final Moisture Content (%)	17,41138458	17,75326538	16,06426239
Wet Weight of Ring + Soil (g)	230,5700073	222,2400055	228,3399963
Moist Weight (g)	24,32999992	28,43000031	28,25
Dry Weight (g)	56,40653229	70,47880554	54,65874481
Wet Density (g/cm³)	48,04179001	59,85295105	47,0935173
Saturation (%)	-50,20124817	-50,58784485	-46,37320328
Void Ratio	-0,943382621	-0,954555273	-0,942242563
Porosity (%)	-1666,242188	-2100,476318	-1631,379272

Figure 51 - Direct Shear Worksheet

4.4.10 Triaxial shear testing

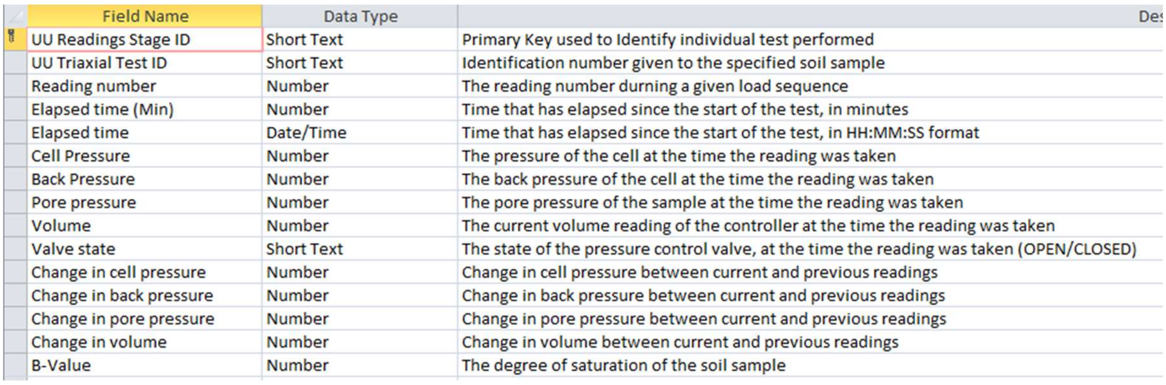
Triaxial works similarly to the previous tables using a secondary table linked to the first table through a one-to-many relationship. The triaxial tables work differently from the other tables as there were three different variations of the test. The fields allow the user to identify which of the four tests were used as a record. This allows the ISGE interface to calculate the results appropriately. These records varied depending on whether shear, saturation and/or consolidation phases were used during the testing, as these were the phases that differentiate the tests.



Field Name	Data Type	
Triaxial Test ID	Short Text	Primary Key used to Identify individual test performed
Sample ID	Short Text	Identification number given to the specified soil sample
Test procedure conducted	Short Text	The type of tet conducted (CU, CD, UU)
Sample type	Short Text	The type of sample used (Undisturbed/Remoulded)
Moulding date	Date/Time	The date the samle was prepared
Test date	Date/Time	The date the sample was tested
Specific Gravity	Number	The specific gravity of the sample soil, as measured
Test Temperature	Number	The temperature of the testing area, as measured
Membrane Thickness	Number	The thickness of the membrane used to contain the sample
Top cap weight	Number	The weight of the Top Cap placed on the sample
Height	Number	The height of the sample
Diameter	Number	The diameter of the sample
Area	Calculated	The area of the sample from a top down view
Volume	Calculated	The volume of the sample
Weight of Moisture tin	Number	Weight of the moisture tine used
Weight of WS and Moisture tir	Number	Weight of wet soil with the moisture tin
Weight of DS and Moisture Tin	Number	Weight of wet soil with the moisture tin
Moisture Content (Ini)	Calculated	Moisture content of the soil as calculated in software
Initial Moist Weight	Number	Weight of the sample prior to the test being done
Dry Density	Number	The density of the given soil sample as calculated in software
Wet density	Number	The density of the given soil sample as calculated in software
Saturation	Number	The degree of saturation
Void Ratio	Number	The ratio of air and water to solids
Initial Burette Reading (Sat)	Number	Burette reading at the start of the saturation phase, as determined in software
Final Burette reading (Sat)	Number	Burette reading at the end of the saturation phase, as determined in software
Initial reference height (Sat)	Number	Height of sample as read by the LVDT, at the start of the saturation phase
Final reference height (Sat)	Number	Height of sample as read by the LVDT, at the end of the saturation phase
Height (Sat)	Number	The corrected height of the sample after saturation
Area (Sat)	Number	The corrected area of the sample after saturation
Volume (Sat)	Number	The corrected volume of the sample after saturation
B-Value	Number	The degree of saturation of the sample, as determined in software
Cell Pressure	Number	The pressure applied to the cell

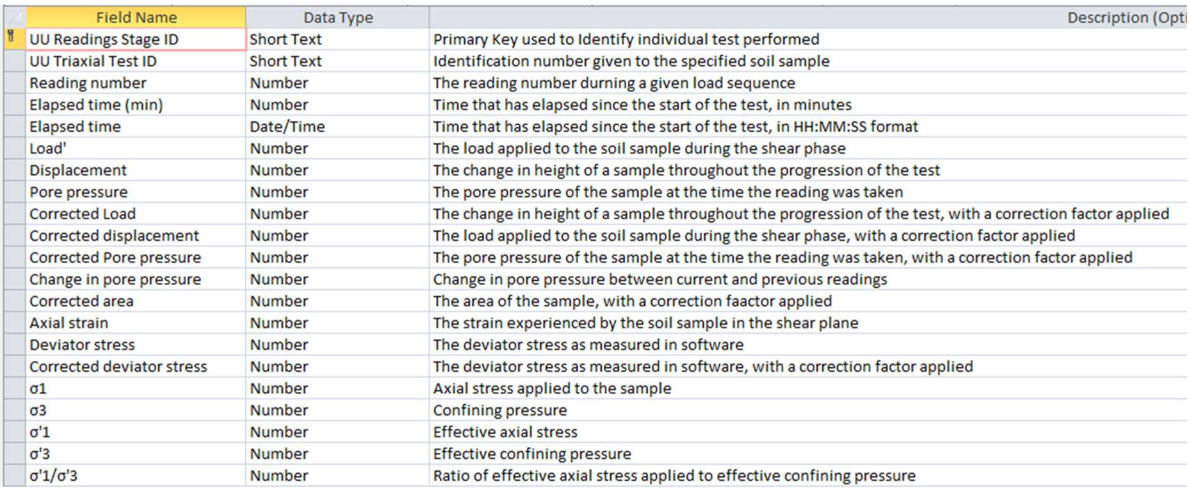
Figure 52 – Triaxial database table

The additional tables (Figures 53, 54 and 55) store values from the saturation, consolidation, and shear phases.



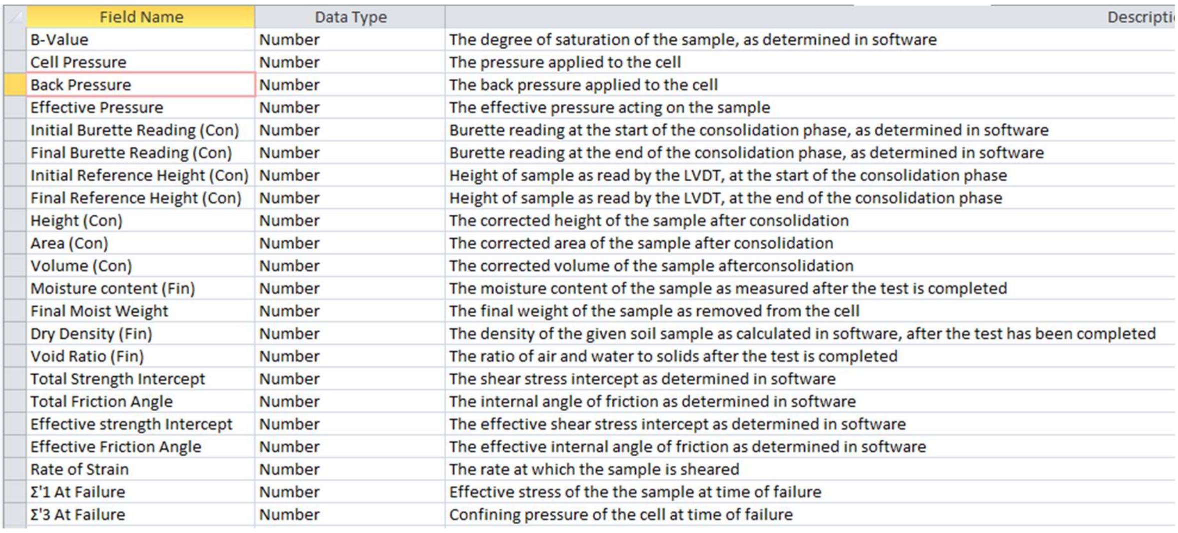
Field Name	Data Type	Des
UU Readings Stage ID	Short Text	Primary Key used to Identify individual test performed
UU Triaxial Test ID	Short Text	Identification number given to the specified soil sample
Reading number	Number	The reading number durning a given load sequence
Elapsed time (Min)	Number	Time that has elapsed since the start of the test, in minutes
Elapsed time	Date/Time	Time that has elapsed since the start of the test, in HH:MM:SS format
Cell Pressure	Number	The pressure of the cell at the time the reading was taken
Back Pressure	Number	The back pressure of the cell at the time the reading was taken
Pore pressure	Number	The pore pressure of the sample at the time the reading was taken
Volume	Number	The current volume reading of the controller at the time the reading was taken
Valve state	Short Text	The state of the pressure control valve, at the time the reading was taken (OPEN/CLOSED)
Change in cell pressure	Number	Change in cell pressure between current and previous readings
Change in back pressure	Number	Change in back pressure between current and previous readings
Change in pore pressure	Number	Change in pore pressure between current and previous readings
Change in volume	Number	Change in volume between current and previous readings
B-Value	Number	The degree of saturation of the soil sample

Figure 53 – Triaxial readings (saturation phase) database table



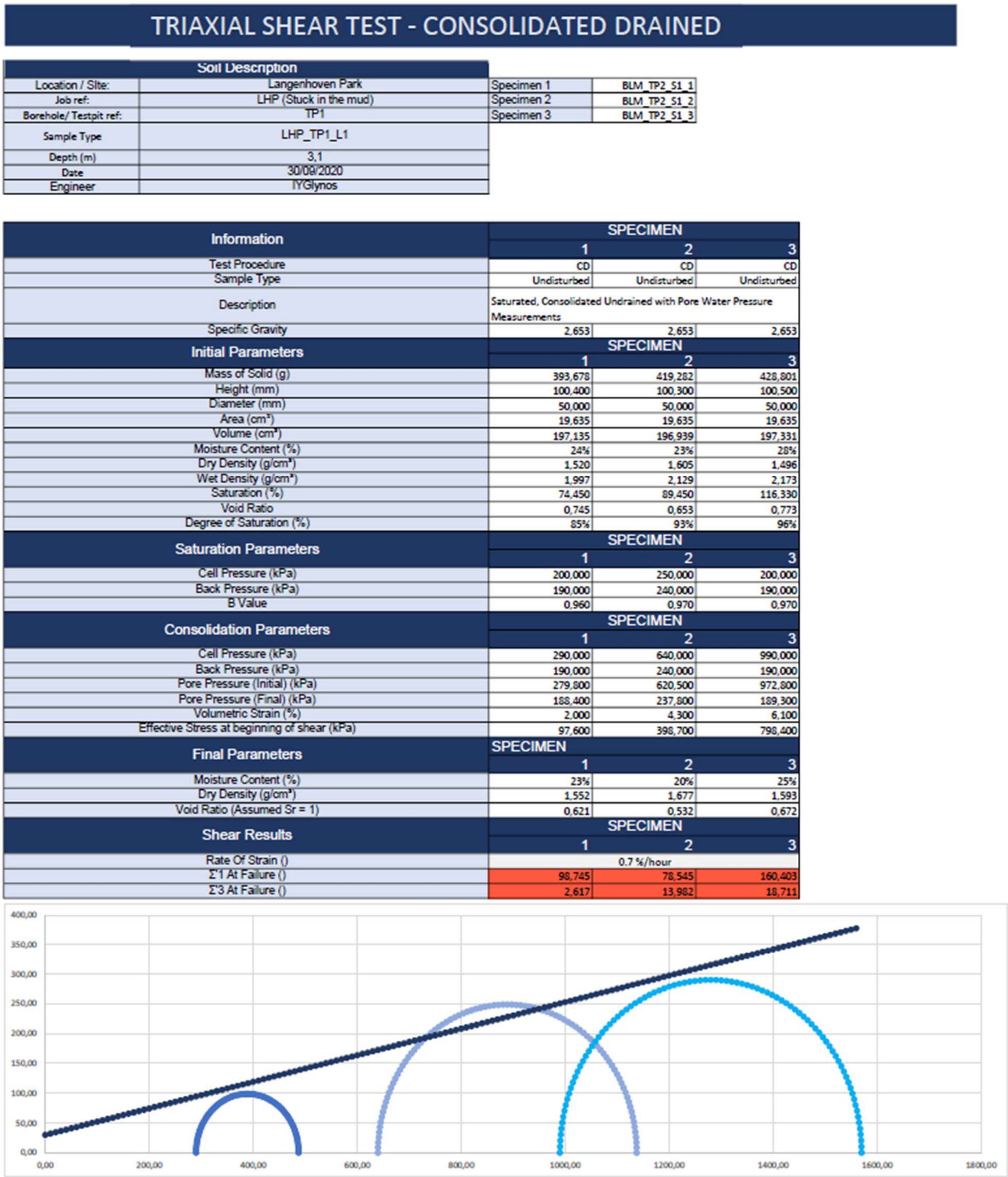
Field Name	Data Type	Description (Opti
UU Readings Stage ID	Short Text	Primary Key used to Identify individual test performed
UU Triaxial Test ID	Short Text	Identification number given to the specified soil sample
Reading number	Number	The reading number durning a given load sequence
Elapsed time (min)	Number	Time that has elapsed since the start of the test, in minutes
Elapsed time	Date/Time	Time that has elapsed since the start of the test, in HH:MM:SS format
Load'	Number	The load applied to the soil sample during the shear phase
Displacement	Number	The change in height of a sample throughout the progression of the test
Pore pressure	Number	The pore pressure of the sample at the time the reading was taken
Corrected Load	Number	The change in height of a sample throughout the progression of the test, with a correction factor applied
Corrected displacement	Number	The load applied to the soil sample during the shear phase, with a correction factor applied
Corrected Pore pressure	Number	The pore pressure of the sample at the time the reading was taken, with a correction factor applied
Change in pore pressure	Number	Change in pore pressure between current and previous readings
Corrected area	Number	The area of the sample, with a correction faactor applied
Axial strain	Number	The strain experienced by the soil sample in the shear plane
Deviator stress	Number	The deviator stress as measured in software
Corrected deviator stress	Number	The deviator stress as measured in software, with a correction factor applied
σ1	Number	Axial stress applied to the sample
σ3	Number	Confining pressure
σ'1	Number	Effective axial stress
σ'3	Number	Effective confining pressure
σ'1/σ'3	Number	Ratio of effective axial stress applied to effective confining pressure

Figure 54 - Triaxial readings (consolidation phase) database table



Field Name	Data Type	Descripti
B-Value	Number	The degree of saturation of the sample, as determined in software
Cell Pressure	Number	The pressure applied to the cell
Back Pressure	Number	The back pressure applied to the cell
Effective Pressure	Number	The effective pressure acting on the sample
Initial Burette Reading (Con)	Number	Burette reading at the start of the consolidation phase, as determined in software
Final Burette Reading (Con)	Number	Burette reading at the end of the consolidation phase, as determined in software
Initial Reference Height (Con)	Number	Height of sample as read by the LVDT, at the start of the consolidation phase
Final Reference Height (Con)	Number	Height of sample as read by the LVDT, at the end of the consolidation phase
Height (Con)	Number	The corrected height of the sample after consolidation
Area (Con)	Number	The corrected area of the sample after consolidation
Volume (Con)	Number	The corrected volume of the sample afterconsolidation
Moisture content (Fin)	Number	The moisture content of the sample as measured after the test is completed
Final Moist Weight	Number	The final weight of the sample as removed from the cell
Dry Density (Fin)	Number	The density of the given soil sample as calculated in software, after the test has been completed
Void Ratio (Fin)	Number	The ratio of air and water to solids after the test is completed
Total Strength Intercept	Number	The shear stress intercept as determined in software
Total Friction Angle	Number	The internal angle of friction as determined in software
Effective strength Intercept	Number	The effective shear stress intercept as determined in software
Effective Friction Angle	Number	The effective internal angle of friction as determined in software
Rate of Strain	Number	The rate at which the sample is sheared
Σ'1 At Failure	Number	Effective stress of the the sample at time of failure
Σ'3 At Failure	Number	Confining pressure of the cell at time of failure

Figure 55 - Triaxial readings (shear phase) database table



TRIAXIAL SHEAR TEST - CONSOLIDATED DRAINED

Soil Description			
Location / Site:	Langenhoven Park	Specimen 1	BLM_TP2_S1_1
Job ref:	LHP (Stuck in the mud)	Specimen 2	BLM_TP2_S1_2
Borehole/ Testpit ref:	TP1	Specimen 3	BLM_TP2_S1_3
Sample Type	LHP_TP1_L1		
Depth (m)	3,1		
Date	30/09/2020		
Engineer	IYGlynos		

Information	SPECIMEN		
	1	2	3
Test Procedure	CD	CD	CD
Sample Type	Undisturbed	Undisturbed	Undisturbed
Description	Saturated, Consolidated Undrained with Pore Water Pressure Measurements		
Specific Gravity	2,653	2,653	2,653
Initial Parameters	**SPECIMEN**		
	1	2	3
Mass of Solid (g)	393,678	419,282	428,801
Height (mm)	100,400	100,300	100,500
Diameter (mm)	50,000	50,000	50,000
Area (cm²)	19,635	19,635	19,635
Volume (cm³)	197,135	196,939	197,331
Moisture Content (%)	24%	23%	28%
Dry Density (g/cm³)	1,520	1,605	1,496
Wet Density (g/cm³)	1,997	2,129	2,173
Saturation (%)	74,450	89,450	116,330
Void Ratio	0,745	0,653	0,773
Degree of Saturation (%)	85%	93%	96%
Saturation Parameters	**SPECIMEN**		
	1	2	3
Cell Pressure (kPa)	200,000	250,000	200,000
Back Pressure (kPa)	190,000	240,000	190,000
B Value	0,960	0,970	0,970
Consolidation Parameters	**SPECIMEN**		
	1	2	3
Cell Pressure (kPa)	290,000	640,000	990,000
Back Pressure (kPa)	190,000	240,000	190,000
Pore Pressure (Initial) (kPa)	279,800	620,500	972,800
Pore Pressure (Final) (kPa)	188,400	237,800	189,300
Volumetric Strain (%)	2,000	4,300	6,100
Effective Stress at beginning of shear (kPa)	97,600	398,700	798,400
Final Parameters	**SPECIMEN**		
	1	2	3
Moisture Content (%)	23%	20%	25%
Dry Density (g/cm³)	1,552	1,677	1,593
Void Ratio (Assumed Sr = 1)	0,621	0,532	0,672
Shear Results	**SPECIMEN**		
	1	2	3
Rate Of Strain ()	0.7 %/hour		
Σ'1 At Failure ()	98,745	78,545	160,403
Σ'3 At Failure ()	2,617	13,982	18,711

Figure 56 – Triaxial Worksheet

All the figures clearly show the processed data that was used from the research group at the Central University of Technology or the duplicate sampling from the partner soil testing laboratory. These sources of data allowed the ISGE to be tested and adjusted to fit real-world data. This is just fundamental testing which showed that the system works but through future studies the system will be improved to adapt to even more types of data.

The important structure of the database has now been created. This serves as the baseline structure for future development of the ISGE. More geotechnical engineering tests and other important properties can be built into the system.

CHAPTER 5: FINAL OUTPUTS

The final outputs required from the database include the Summary sheet, the exported CSV files for GIS software and an adaptable system that can be developed further for geotechnical engineers to make better decisions.

Additional sheets were made for linked data from the Access database. This occurs when any data is queried from an external source. A sheet was made for each table from the database. These sheets automatically update any data added to the database. The database prevents any information from being lost permanently. The Excel sheets search for the required data from the linked tables through Lookup functions, allowing any sample's data stored in the database to be transformed into information for the geotechnical engineer.

The linked tables have additional columns for calculations. These calculations were used in the final worksheet (ISGE Table), which was exported as a file. This file could be used for GIS purposes.

The final products of the system are the CSV or text files (used for GIS overlays) and the summary page that can be used to visualise data in the area for better decision-making during desktop studies. Additionally, the worksheets are preliminary outputs, as they show the transformed data which is now useful information.

The CSV (refer to annexure for CSV file example) file is imported into Geographical Information System (GIS) software. QGIS was used when testing the file and for demonstration because it is a freely available GIS software that has similar functionality to most. QGIS provides common functions and features for GIS. It is being used by many engineers and other experts daily. QGIS supports several raster and vector data formats, with new format support added using the plugin architecture. This software is therefore an appropriate software for testing the CSV files. (Cutts, 2019)

The data is added to an attribute table which can be viewed as point data that represents each test pit point. Selecting a point can show all geotechnical engineering information about the point or test pit. This information about the point can be compared to other points within the system or the summary pages on the Excel sheet for a complete assessment of all geotechnical parameters in the area being studied. The points could then be used for creating heat maps of specific outputs (e.g. plastic index values in a selected area).

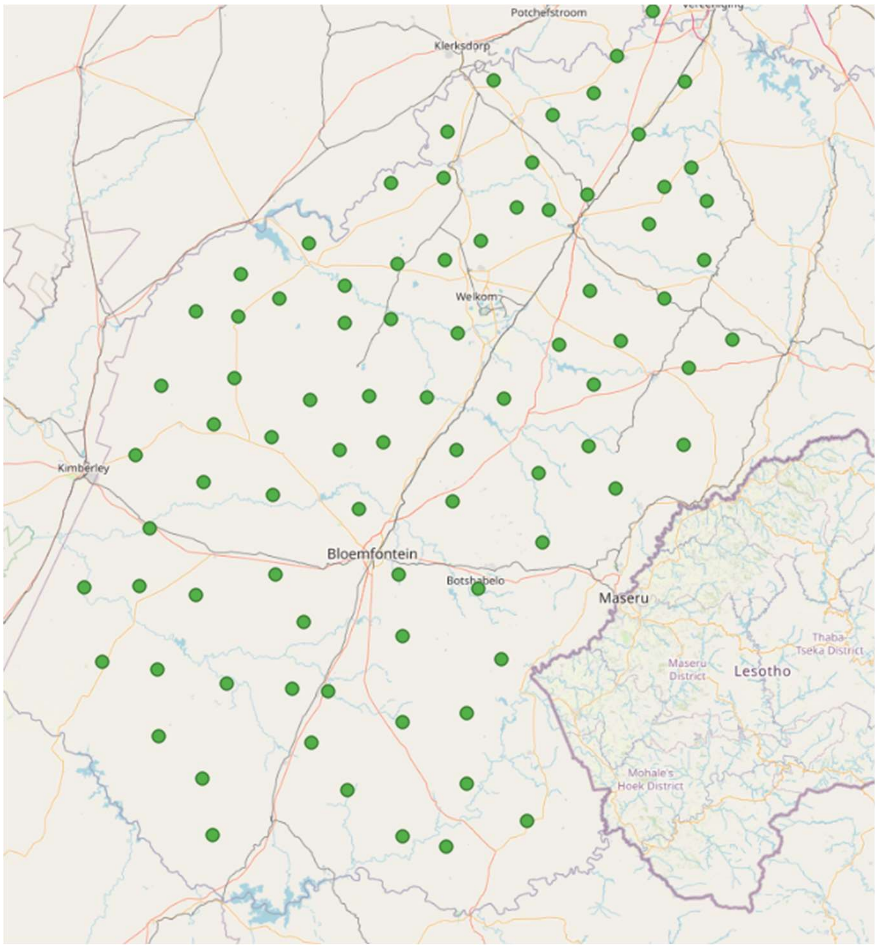


Figure 57 – Test pits imported as points in QGIS software in the Free State area

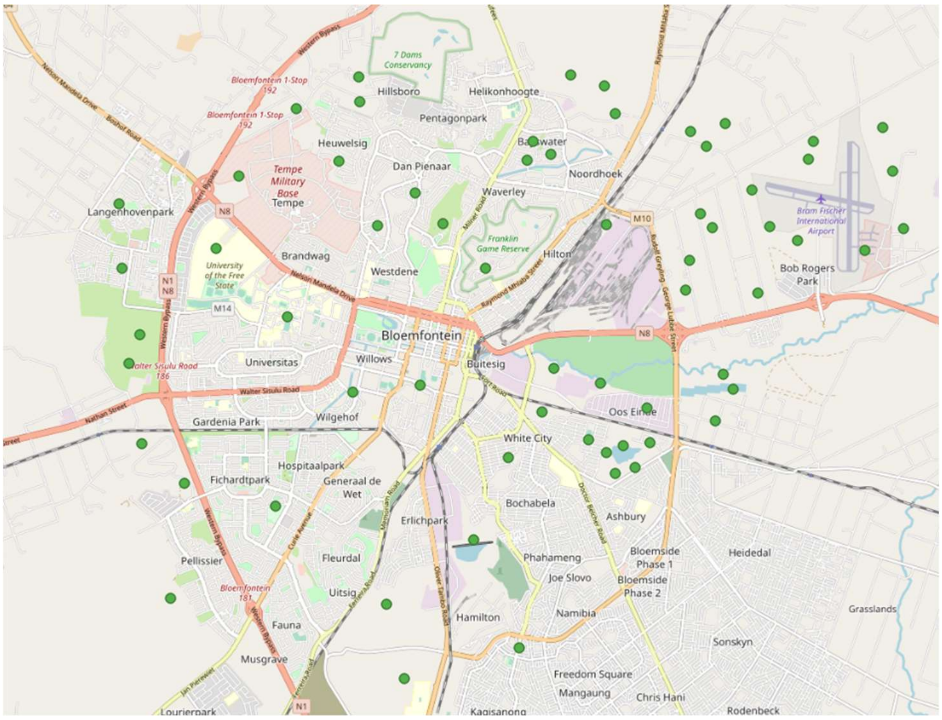
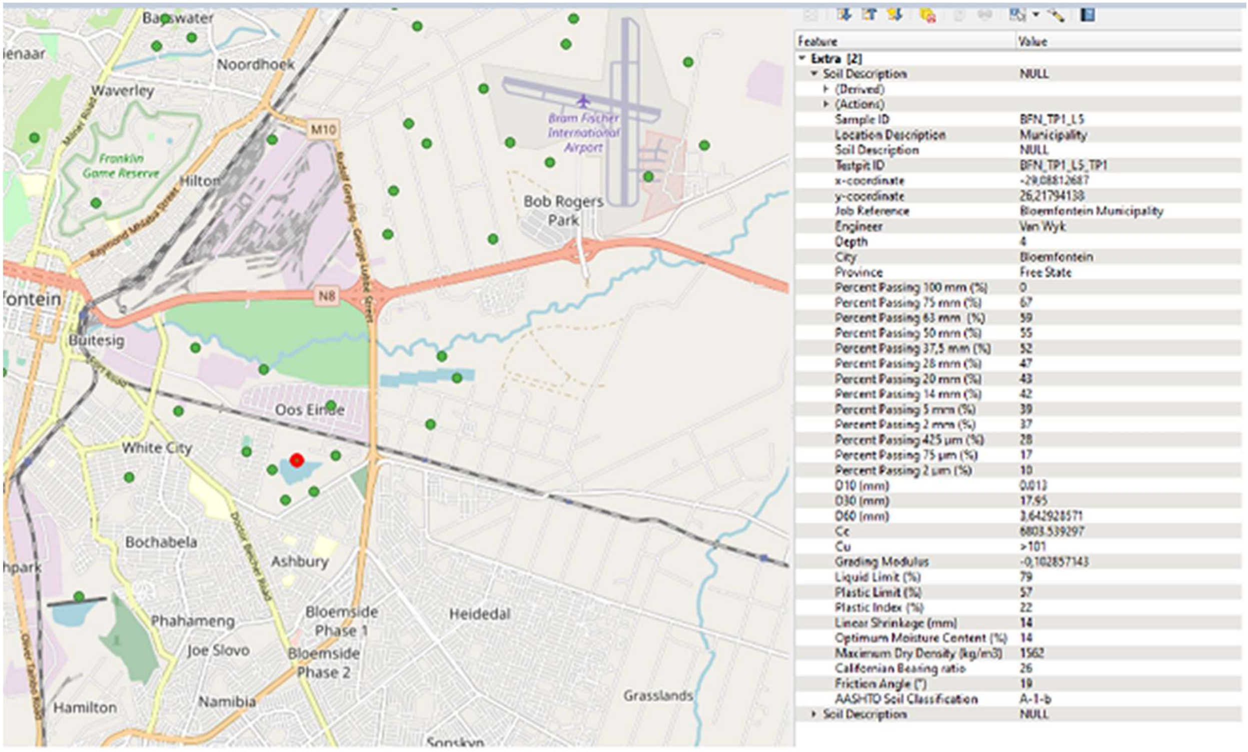


Figure 58 – Imported data around the Bloemfontein area



Feature	Value
Extra [2]	
Soil Description	NULL
(Derived)	
(Actions)	
Sample ID	BFN_TP1_L5
Location Description	Municipality
Soil Description	NULL
Testpit ID	BFN_TP1_L5_TP1
x-coordinate	-29,08812687
y-coordinate	26,21794138
Job Reference	Bloemfontein Municipality
Engineer	Van Wyk
Depth	4
City	Bloemfontein
Province	Free State
Percent Passing 100 mm (%)	0
Percent Passing 75 mm (%)	67
Percent Passing 63 mm (%)	59
Percent Passing 50 mm (%)	55
Percent Passing 37,5 mm (%)	52
Percent Passing 28 mm (%)	47
Percent Passing 20 mm (%)	43
Percent Passing 14 mm (%)	42
Percent Passing 5 mm (%)	39
Percent Passing 2 mm (%)	37
Percent Passing 425 µm (%)	28
Percent Passing 75 µm (%)	17
Percent Passing 2 µm (%)	10
D10 (mm)	0,013
D30 (mm)	17,95
D60 (mm)	3,642928571
Cc	6803,539297
Cu	>101
Grading Modulus	-0,102857143
Liquid Limit (%)	79
Plastic Limit (%)	57
Plastic Index (%)	22
Linear Shrinkage (mm)	14
Optimum Moisture Content (%)	14
Maximum Dry Density (kg/m3)	1562
Californian Bearing ratio	26
Friction Angle (°)	19
AASHTO Soil Classification	A-1-b
Soil Description	NULL

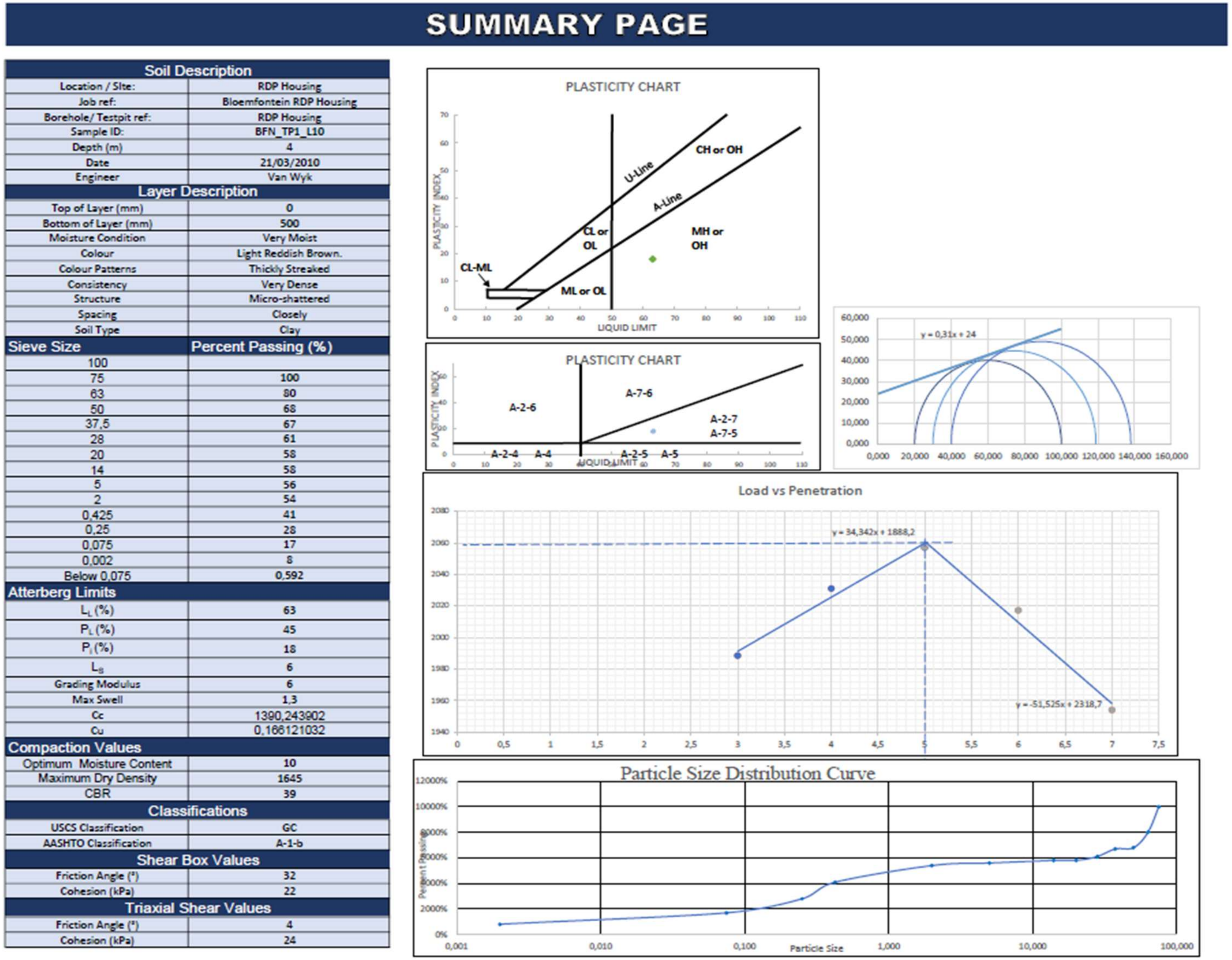
Figure 59 – Data shown of selected test pits

Summary Page

The summary page (See Figure 60) consolidates all the information in the information system into one sheet. The most important outputs and final results from the tests, the site investigation and the manipulation are shown together as one sheet for better use and decision-making. The page firstly shows sample data with all the critical information describing the soil. The sheet shows the particle size distribution growth with its detain D30 and D60 values and gives the CU and CC values. The Atterberg limits' final values (i.e. the liquid limits, plastic limit and plasticity index) are also shown. The two charts for the plasticity are shown, which classify the soil according to the values determined through the test. All these criteria are essential for the classification of soil. They are also used for the USCS and the AASHTO classifications, which are also determined on the summary sheet. The maximum dry density and optimum moisture content values are also given. The CBR values give important values should the soils be needed in a compaction scenario.

All the information, fundamental values or descriptions required by the engineer to make critical decisions are shown on the summary page. The criteria in this sheet are especially important to South African engineers as they focused on the SANS3001 codes and SAICE Code of Practice standards which are not used by available software in other countries.

The summary page improves decision making as all the information can be easily searched through the linked database, which is also unique in a South African context.



SUMMARY PAGE

Soil Description	
Location / Site:	RDP Housing
Job ref:	Bloemfontein RDP Housing
Borehole/ Testpit ref:	RDP Housing
Sample ID:	BFN_TP1_L10
Depth (m)	4
Date	21/03/2010
Engineer	Van Wyk
Layer Description	
Top of Layer (mm)	0
Bottom of Layer (mm)	500
Moisture Condition	Very Moist
Colour	Light Reddish Brown.
Colour Patterns	Thickly Streaked
Consistency	Very Dense
Structure	Micro-shattered
Spacing	Closely
Soil Type	Clay
Sieve Size	**Percent Passing (%)**
100	
75	100
63	80
50	68
37,5	67
28	61
20	58
14	58
5	56
2	54
0,425	41
0,25	28
0,075	17
0,002	8
Below 0,075	0,592
Atterberg Limits	
L_L (%)	63
P_L (%)	45
P_I (%)	18
L_S	6
Grading Modulus	6
Max Swell	1,3
Cc	1390,243902
Cu	0,166121032
Compaction Values	
Optimum Moisture Content	10
Maximum Dry Density	1645
CBR	39
Classifications	
USCS Classification	GC
AASHTO Classification	A-1-b
Shear Box Values	
Friction Angle (°)	32
Cohesion (kPa)	22
Triaxial Shear Values	
Friction Angle (°)	4
Cohesion (kPa)	24

Figure 60 - Summary page example

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Aims and Objectives

The following Hypothesis, Aim and Objectives were presented at the beginning of the study:

6.1.1 Hypothesis

An ISGE will assist South African engineers to compare and analyse geotechnical engineering information during the decision-making process of desktop studies.

6.1.2 Research aim

To develop an ISGE to be used by South African geotechnical engineers to assist them in making informed decisions during the desktop study.

6.1.2.1 Objective 1

To determine necessary tests and parameters for making informed decisions in geotechnical investigations. All these ‘entities’ will be measured on SANS3001 standards and regulations in South Africa.

6.1.2.2 Objective 2

To design and create a geotechnical engineering database to store geotechnical engineering test and site data.

6.1.2.3 Objective 3

To develop an information interface that transforms data from the information in the database to create geotechnical outputs expected by geotechnical engineers and display them.

6.1.2.4 Objective 4

To create a summary page interface that summarises the geotechnical information to improve decision-making during a desktop study.

6.1.2.5 Objective 5

To develop the capability for the system to export the information in a file format supported by GIS software for comparison of information near areas studied by the engineer during a desktop study.

6.2 Consolidation of Aims and Objectives

The study started with the goal to develop an ISGE that would assist South African engineers to compare and analyse geotechnical engineering information during the decision-making process of a desktop study. The ISGE would assist engineers in desk studies by identifying sites and potential risks and enabling the engineer to make decisions on the approach of the site investigation by accessing a wealth of engineering data and charts.

6.2.1.1 Objective 1

The necessary tests and parameters for making informed decisions in geotechnical investigations were determined. All these tests were assessed according to the SANS3001 standards and the regulations in South Africa. Each test procedure was studied, and all the necessary inputs and outputs were determined. Many procedures or tests had specific results (outputs) such as graphs or charts that needed to be shown visually. These were studied to be developed effectively into the ISGE.

During this study, it became clear that an information system should be put into place to assist with the effective management of data that has spatial information. The system should transform the data into the required outputs of the tests (especially SANS3001 standard tests) and give important engineering insight that assists decision-making. Unfortunately, the available systems do not provide much assistance to decision-makers, especially in a South African context.

6.2.1.2 Objective 2

The geotechnical engineering database was developed using Microsoft Access to store the geotechnical engineering test and site data. The database was designed by creating tables and fields for each of the geotechnical tests or procedures. There are many advantages to developing a database for the ISGE. The system can store large numbers of records efficiently which means that thousands of geotechnical records can be stored without using much memory space on the computer. This eliminates the need for physical space for paper filing. The database allows users to find specific information quickly (when they need to search locations or specific geotechnical values) and with ease and enables them to sort through the data easily to process existing data to facilitate decision-making. Databases are very secure and can prevent users from accidentally deleting records or accessing private information. Owing to databases working efficiently with other applications, it allows the ISGE to include other applications such as Microsoft Excel for further manipulation and processing of data.

6.2.1.3 Objective 3

An information interface that transforms data from the information in the database to create geotechnical outputs on Microsoft Excel was developed and linked to the database. This interface system accessed the different tables developed in the database to create worksheets for each test procedure specified for the ISGE that is required by South African geotechnical engineers. This allows the user to search for any existing samples, layers or test pits and view the relevant inputs (laboratory or site information or readings), calculations, and outputs (parameters, estimations and charts) for those tests.

6.2.1.4 Objective 4

To improve decision-making, a summary page interface that summarises the geotechnical information was developed in the information interface as well. This access to information allows engineers to observe a large quantity of different information in detail to compare and make a comprehensive assessment of the site and all the geotechnical properties of that area.

6.2.1.5 Objective 5

The ISGE has the capability to export the information in a file format (.csv file) supported by GIS software for comparison of information near areas studied by the engineer during a desktop study. Using GIS makes interpreting the potential problems of areas much easier for engineers who can observe the surrounding data and make valid assumptions about their study areas. For example, an engineer could assess the potential expansiveness of the surrounding areas and suggest different designs to prevent excessive heave on a structure or road, request more test pits to assess the types of soils on the site properly or predict which areas could be the most susceptible to heave.

6.2.2 Aim & Hypithesis

The ISGE was developed with all the specifications identified during the literature review to assist South African geotechnical engineers (and other experts). The database and interface use the SANS3001 codes which are currently not available in other software, as determined through a thorough study of the available software. It stores data for other engineers to view and it transforms the data into useful information such as charting. The data can also be exported into GIS software for engineers to view the data in different maps and compare it to different existing data. Engineers will be able to compare any other relevant geotechnical data from previous works on and around the site being studied.

With the ISGE in place, data can now be stored and transformed for decision-making. The data will be added by the data administrator (the author) as the users will only access the data through the interface and future mapping capabilities. The literature review about available information systems provided much-needed information about the current systems used and the availability of these systems for South African engineers.

6.3 Future Prospects of the ISGE

The ISGE was developed to allow expansion to other fields of engineering and other relevant fields. The purpose of this project was to develop a foundation for a system that will be a wealth of knowledge accessible to engineers and other experts by means of a central system, allowing them to access more information to use across the country. The development of the ISGE could initiate a longer-term advancement of the system that creates a national transfer of information to all engineering professions which would improve the quality of engineering decisions.

The study has shown that geotechnical engineering-based software is limited in terms of South African requirements for an information system, especially in terms of SANS3001 codes as well as access to geotechnical data in a GIS format such as basemaps. The ISGE will allow the transfer of information through base maps (similar to the Kentucky Transportation Basemap system) where engineers could view the data to make decisions and share the information. Transferring data into GIS is a useful capability in a world where GIS is becoming a core tool in any engineering project.

As the ISGE further advances, it will contribute to providing South African engineers with a wealth of geotechnical information (especially focused on SANS3001 codes) which has never been produced before. The next steps in the advancement of the system will include the addition of laboratory test and site data, from different regions in South Africa (starting in the Free State), to the ISGE database.

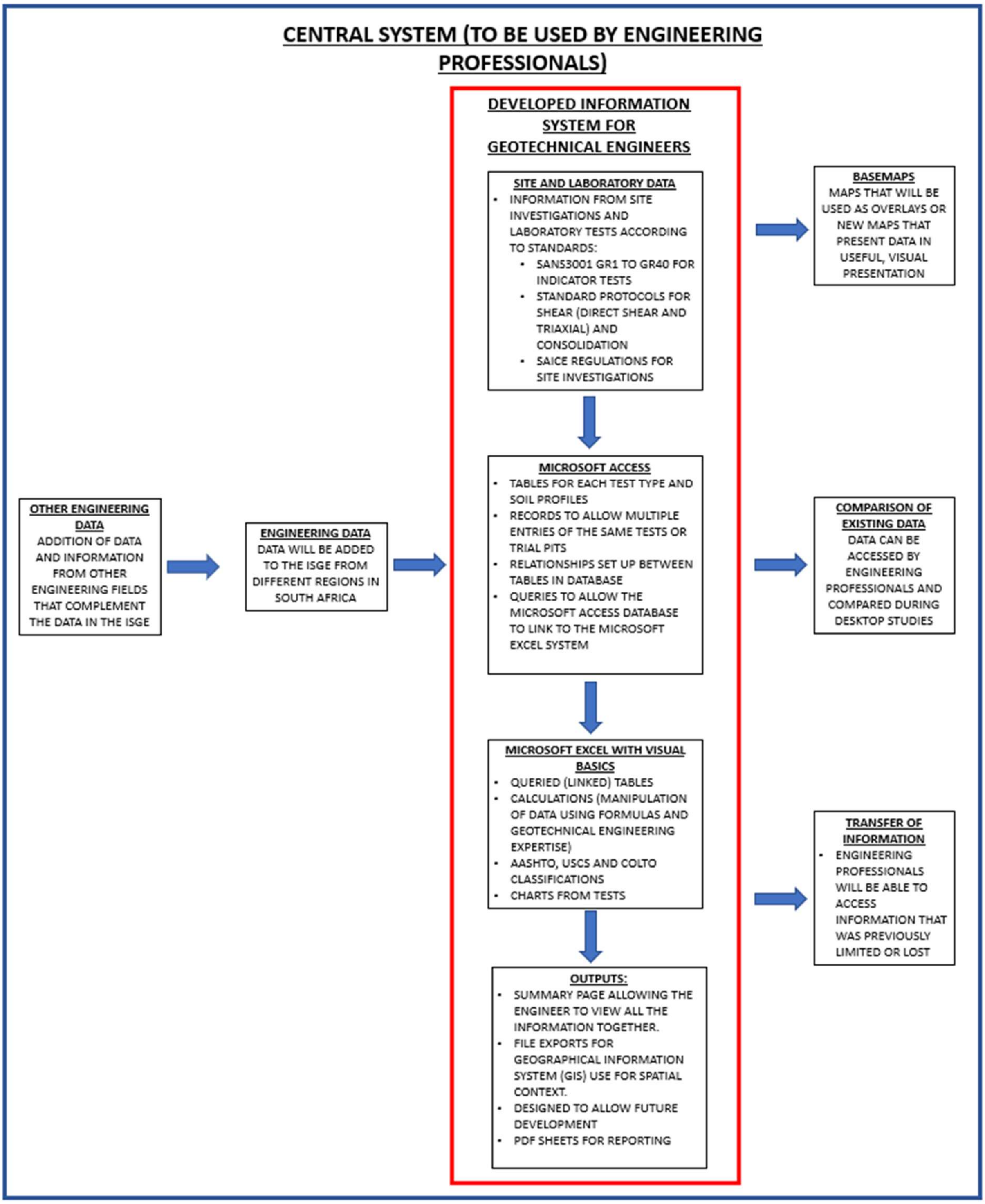


Figure 61 - Future prospects for the ISGE

The database will be developed into a central database where a network of engineers could access the data and add more data to the database for a national transfer of information. The addition of data from different regions around the country produces more mapping options (such as GIS plugins) or base maps.

6.4 Conclusion

The ISGE was developed to be used by South African geotechnical engineers to assist them in making informed decisions during the desktop study phase. A comparison study was done to assess the existing information systems and determine if the needs of South African engineers were met. The database and interface were conceptualized and created with a primary focus on SANS3001 standards. Database tables were designed and created for each of the standard SANS3001 geotechnical engineering tests, advanced geotechnical tests and testpit profiles. These tables were linked to primary table that contained all the important data for the layer of the testpit from which it originated. The interface allows the user to query data from the database and convert it into useful information in form of charts, tables and calculated results.

The system allows the user to manage and store the data, allowing the user to compare all relevant site and laboratory information during desktop studies to improve their decision-making. With the ISGE designed and its potential to further develop into a central system, it could become one of the most significant tools in the daily lives of South African engineers.

CHAPTER 7: REFERENCES

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APPENDIX A - TABULATED FORMULAS FOR ISGE

Coding for AASHTO Classification

```
Function AASHTO(SieveTen As Integer, SieveForty As Integer, SieveTwoHundred As Integer, LiquidLimit As Integer, PlasticityIndex As Integer) As String

    'Less than or equal to 35%

    If SieveTwoHundred <= 35 And SieveTen <= 50 And SieveForty <= 30 And SieveTwoHundred <= 15 And PlasticityIndex <= 6 Then

        AASHTO = "A-1-a"

    ElseIf SieveTwoHundred <= 35 And SieveForty <= 50 And SieveTwoHundred <= 25 Then

        AASHTO = "A-1-b"

    ElseIf SieveTwoHundred <= 35 And SieveForty >= 51 And SieveTwoHundred <= 10 And PlasticityIndex <= 10 Then

        AASHTO = "A-3"

    ElseIf SieveTwoHundred <= 35 And SieveTwoHundred <= 35 And LiquidLimit <= 40 And PlasticityIndex <= 10 Then

        AASHTO = "A-2-4"

    ElseIf SieveTwoHundred <= 35 And SieveTwoHundred <= 35 And LiquidLimit >= 41 And PlasticityIndex = 11 Then

        AASHTO = "A-2-5"

    ElseIf SieveTwoHundred <= 35 And SieveTwoHundred <= 35 And LiquidLimit <= 40 And PlasticityIndex = 11 Then

        AASHTO = "A-2-6"

    ElseIf SieveTwoHundred <= 35 And SieveTwoHundred <= 35 And LiquidLimit >= 41 And PlasticityIndex <= 10 Then

        AASHTO = "A-2-7"

        'More than 35%

    ElseIf SieveTwoHundred > 35 And SieveTwoHundred >= 36 And LiquidLimit <= 40 And PlasticityIndex <= 10 Then

        AASHTO = "A-4"

    ElseIf SieveTwoHundred > 35 And SieveTwoHundred >= 36 And LiquidLimit >= 41 And PlasticityIndex > 11 Then

        AASHTO = "A-5"
```

```
    ElseIf SieveTwoHundred > 35 And SieveTwoHundred >= 36 And LiquidLimit <= 40 And PlasticityIndex > 11 Then
        AASHTO = "A-6"
    ElseIf PlasticityIndex <= (LiquidLimit - 30) Then
        AASHTO = "A-7-5"
    ElseIf PlasticityIndex > (LiquidLimit - 30) Then
        AASHTO = "A-7-6"
    Else
        AASHTO = "Not Working"

End If
End Function
```

Coding for USCS Classification

```
Function USCS(LiquidLimitUSCS As Integer, Organic As Boolean, SieveTwoHundredUSCS As Integer, PI As Integer, Sand As Integer, Gravel As Integer) As String
    'CL
        If LiquidLimitUSCS < 50 And PI > 7 And SieveTwoHundredUSCS < 15 And Organic = True Then
            USCS = "Lean Clay"
    ElseIf LiquidLimitUSCS < 50 And PI > 7 And 15 <= SieveTwoHundredUSCS < 30 And Sand >= Gravel And Organic = True Then
            USCS = "Lean Clay with Sand"
    ElseIf LiquidLimitUSCS < 50 And PI > 7 And 15 <= SieveTwoHundredUSCS < 30 And Sand < Gravel And Organic = True Then
            USCS = "Lean Clay with Gravel"
    ElseIf LiquidLimitUSCS < 50 And PI > 7 And SieveTwoHundredUSCS >= 30 And Sand >= Gravel And Gravel < 15 And Organic = True Then
            USCS = "Sandy Lean Clay"
    ElseIf LiquidLimitUSCS < 50 And PI > 7 And SieveTwoHundredUSCS >= 30 And Sand >= Gravel And Gravel >= 15 And Organic = True Then
            USCS = "Sandy Lean Clay with Gravel"
    ElseIf LiquidLimitUSCS < 50 And PI > 7 And SieveTwoHundredUSCS >= 30 And Sand < Gravel And Sand < 15 And Organic = True Then
            USCS = "Gravelly Lean Clay"
    ElseIf LiquidLimitUSCS < 50 And PI > 7 And SieveTwoHundredUSCS >= 30 And Sand < Gravel And Sand >= 15 And Organic = True Then
            USCS = "Gravelly Lean Clay with Sand"


    'CL - ML
        If LiquidLimitUSCS < 50 And 4 <= PI <= 7 And SieveTwoHundredUSCS < 15 And Organic = True Then
            USCS = "Silty Clay"
    ElseIf LiquidLimitUSCS < 50 And 4 <= PI <= 7 And 15 <= SieveTwoHundredUSCS < 30 And Sand >= Gravel And Organic = True Then
            USCS = "Silty Clay with Sand"
```

```
    ElseIf LiquidLimitUSCS < 50 And 4 <= PI <= 7 And 15 <= SieveTwoHundredUSCS < 30 And Sand < Gravel And Organic = True Then
            USCS = "Silty Clay with Gravel"
    ElseIf LiquidLimitUSCS < 50 And 4 <= PI <= 7 And SieveTwoHundredUSCS >= 30 And Sand >= Gravel And Gravel < 15 And Organic = True Then
            USCS = "Sandy Silty Clay"
    ElseIf LiquidLimitUSCS < 50 And 4 <= PI <= 7 And SieveTwoHundredUSCS >= 30 And Sand >= Gravel And Gravel >= 15 And Organic = True Then
            USCS = "Sandy Silty Clay with Gravel"
    ElseIf LiquidLimitUSCS < 50 And 4 <= PI <= 7 And SieveTwoHundredUSCS >= 30 And Sand < Gravel And Sand < 15 And Organic = True Then
            USCS = "Gravelly Silty Clay"
    ElseIf LiquidLimitUSCS < 50 And 4 <= PI <= 7 And SieveTwoHundredUSCS >= 30 And Sand < Gravel And Sand >= 15 And Organic = True Then
            USCS = "Gravelly Silty Clay with Sand"


    'ML
        If LiquidLimitUSCS < 50 And PI < 4 And SieveTwoHundredUSCS < 15 And Organic = True Then
            USCS = "Silty Clay"
    ElseIf LiquidLimitUSCS < 50 And PI < 4 And 15 <= SieveTwoHundredUSCS < 30 And Sand >= Gravel And Organic = True Then
            USCS = "Silty Clay with Sand"
    ElseIf LiquidLimitUSCS < 50 And PI < 4 And 15 <= SieveTwoHundredUSCS < 30 And Sand < Gravel And Organic = True Then
            USCS = "Silty Clay with Gravel"
    ElseIf LiquidLimitUSCS < 50 And PI < 4 And SieveTwoHundredUSCS >= 30 And Sand >= Gravel And Gravel < 15 And Organic = True Then
            USCS = "Sandy Silty Clay"
    ElseIf LiquidLimitUSCS < 50 And PI < 4 And SieveTwoHundredUSCS >= 30 And Sand >= Gravel And Gravel >= 15 And Organic = True Then
            USCS = "Sandy Silty Clay with Gravel"
    ElseIf LiquidLimitUSCS < 50 And PI < 4 And SieveTwoHundredUSCS >= 30 And Sand < Gravel And Sand < 15 And Organic = True Then
```

```
        USCS = "Gravelly Silty Clay"
   ElseIf LiquidLimitUSCS < 50 And 4 <= PI <= 7 And SieveTwoHundredUSCS >= 30 And Sand < Gravel And Sand >= 15 And Organic = True Then
        USCS = "Gravelly Silty Clay with Sand"
   Else
        USCS = "Not Working"
End If
End Function
```

Sieve Analysis

Md (g) (Test Sample Mass)	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],4,FALSE)					
Md1 (g) (Mass of Material Passing 20mm Sieve)	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],5,FALSE)	Sieve Size	Mass on Sieve (g)	Corr. Mass	Percent Retained (%)	Percent Passing (%)
Md1 (g) (Mass of Riffled Material Passing 20mm Sieve)	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],6,FALSE)	100	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],10,FALSE)	=$C$22*E17	=(F17/$C$21)*100	=100-G17
Md3 (g) (Mass of Material Passing 0,425 mm Sieve)	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],7,FALSE)	75	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],11,FALSE)	=$C$22*E18	=(F18/$C$21)*100	=H17-G18
Md4A (g) (Mass of fines used to determine 0.0075mm fraction)	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],8,FALSE)	63	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],12,FALSE)	=$C$22*E19	=(F19/$C$21)*100	=H18-G19
Md4B (g) (Mass of fines used to determine 0.0075mm fraction)	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],9,FALSE)	50	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],13,FALSE)	=$C$22*E20	=(F20/$C$21)*100	=H19-G20
Md9 (g) (Mass of Reduced Sample)	=SUM(F17:F27)+C18	37.5	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],14,FALSE)	=$C$22*E21	=(F21/$C$21)*100	=H20-G21
Rf (no unit) (Reduction Factor)	=C17/C16	28	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],15,FALSE)	=$C$22*E22	=(F22/$C$21)*100	=H21-G22
Md (g) (Mass of Sample With Reduction Factor)	=C15*C22	20	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],16,FALSE)	=$C$22*E23	=(F23/$C$21)*100	=H22-G23
Difference	=(C23-C21)/C21	14	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],17,FALSE)	=E24	=(F24/$C$21)*100	=H23-G24
Check	=IF(((C23-C21)/C21)<0.01," <1% Difference"," >1% Difference")	5	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],18,FALSE)	=E25	=(F25/$C$21)*100	=H24-G25
	=IF(C25=" <1% Difference","Correct","Incorrect")	2	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],19,FALSE)	=E26	=(F26/$C$21)*100	=H25-G26
Outputs		0.425	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],20,FALSE)	=E27	=(F27/$C$21)*100	=H26-G27
D10	=INDEX(H17:H32,MATCH(MIN(ABS(H17:H32-AB1)),ABS(H17:H32-AB1),0))	0.25	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],21,FALSE)	=E28	=(F28/$C$21)*100	=H27-G28
D30	=INDEX(H17:H32,MATCH(MIN(ABS(H17:H32-AB1)),ABS(H17:H32-AB1),0))	0.075	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],22,FALSE)	=E29	=(F29/$C$21)*100	=H28-G29
D60	=INDEX(H17:H32,MATCH(MIN(ABS(H17:H32-AB1)),ABS(H17:H32-AB1),0))	0.002	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],23,FALSE)	=E30	=(F30/$C$21)*100	=H29-G30
Cu	=C30/C28	Below 0,075	=VLOOKUP($C$9,C_Sieve_Analysis_TBL[#All],24,FALSE)	=E31	=(F31/$C$21)*100	=H30-G31
Cc	=(C29^2)/(C30*C28)					

Hydrometer	
P2 (%)	=VLOOKUP($C$9,D_Hydrometer_TBL!A1:AF2,4,FALSE)
Md2 (g)	=VLOOKUP($C$9,D_Hydrometer_TBL!A1:AF2,5,FALSE)
Md3 (g)	=VLOOKUP($C$9,D_Hydrometer_TBL!A1:AF2,6,FALSE)
Mw1 (g)	=VLOOKUP($C$9,D_Hydrometer_TBL!A1:AF2,7,FALSE)
W (%)	=VLOOKUP($C$9,D_Hydrometer_TBL!A1:AF2,8,FALSE)
Relative Density	=VLOOKUP($C$9,D_Hydrometer_TBL!A1:AF2,9,FALSE)
MHD	=L26
PH425 (%)	=100*((L26-L16)/L26)
PH75 (%)	=100*(L26-L16-L17)/L26
PHT 425 (%)	=L22*(L15/100)
PHT75 (%)	=L23*(L15/100)
Md1 (g)	=L18/(1+L19/100)

Time after hour of sedimentation		Hydrometer Reading	Blank Solution Reading	Temperature (°C)
40 sec		=VLOOKUP($C$9,D_Hydrometer_TBL!A1:AF2,10,FALSE)	=VLOOKUP($C$9,D_Hydrometer_TBL!B1:AG2,14,FALSE)	=VLOOKUP($C$9,D_Hydrometer_TBL!C1:AH2,18,FALSE)
2 min		=VLOOKUP($C$9,D_Hydrometer_TBL!A1:AF2,11,FALSE)	=VLOOKUP($C$9,D_Hydrometer_TBL!B1:AG2,15,FALSE)	=VLOOKUP($C$9,D_Hydrometer_TBL!C1:AH2,19,FALSE)
12 min		=VLOOKUP($C$9,D_Hydrometer_TBL!A1:AF2,12,FALSE)	=VLOOKUP($C$9,D_Hydrometer_TBL!B1:AG2,16,FALSE)	=VLOOKUP($C$9,D_Hydrometer_TBL!C1:AH2,20,FALSE)
12 hour		=VLOOKUP($C$9,D_Hydrometer_TBL!A1:AF2,13,FALSE)	=VLOOKUP($C$9,D_Hydrometer_TBL!B1:AG2,17,FALSE)	=VLOOKUP($C$9,D_Hydrometer_TBL!C1:AH2,21,FALSE)
40 sec	D (mm)	=(VLOOKUP(N28,$Q$10:$Z$25,MATCH(L20,$R$10:$Z$10,0)+1,FALSE)) L28<15 (SQRT(VLOOKUP(L28,$Q$29:$R$44,2,FALSE)/2)) L28<31 (SQRT(VLOOKUP(L28,S29:T44,2,FALSE)/2)) L28<47 (SQRT(VLOOKUP(L28,U29:V44,2,FALSE)/2)) L28<31 (SQRT(VLOOKUP(L28,W29:X41,2,FALSE)/2)) "Err		
	RC	=0.62*(L28-M28)		
	Psi (%)	=L33*(100/L21)*(L20/(L20-1))		
	Pi (%)	=L15*(L34/100)		
2 min	D (mm)	=(VLOOKUP(N29,$Q$10:$Z$25,MATCH(L20,$R$10:$Z$10,0)+1,FALSE)) L29<15 (SQRT(VLOOKUP(L29,$Q$29:$R$44,2,FALSE)/2)) L29<31 (SQRT(VLOOKUP(L29,S29:T44,2,FALSE)/2)) L29<47 (SQRT(VLOOKUP(L29,U29:V44,2,FALSE)/2)) L29<31 (SQRT(VLOOKUP(L29,W29:X41,2,FALSE)/2)) "Err		
	RC	=0.62*(L29-M29)		
	Psi (%)	=L37*(100/L21)*(L20/(L20-1))		
	Pi (%)	=L15*(L38/100)		
12 min	D (mm)	=(VLOOKUP(N30,$Q$10:$Z$25,MATCH(L20,$R$10:$Z$10,0)+1,FALSE)) L30<15 (SQRT(VLOOKUP(L30,$Q$29:$R$44,2,FALSE)/2)) L30<31 (SQRT(VLOOKUP(L30,S29:T44,2,FALSE)/2)) L30<47 (SQRT(VLOOKUP(L30,U29:V44,2,FALSE)/2)) L30<31 (SQRT(VLOOKUP(L30,W29:X41,2,FALSE)/2)) "Err		
	RC	=0.62*(L30-M30)		
	Psi (%)	=L41*(100/L21)*(L20/(L20-1))		
	Pi (%)	=L23*(L15/100)		
12 hour	D (mm)	=(VLOOKUP(N31,$Q$10:$Z$25,MATCH(L20,$R$10:$Z$10,0)+1,FALSE)) L31<15 (SQRT(VLOOKUP(L31,$Q$29:$R$44,2,FALSE)/2)) L31<31 (SQRT(VLOOKUP(L31,S29:T44,2,FALSE)/2)) L31<47 (SQRT(VLOOKUP(L31,U29:V44,2,FALSE)/2)) L31<31 (SQRT(VLOOKUP(L31,W29:X41,2,FALSE)/2)) "Err		
	RC	=0.62*(L31-M31)		
	Psi (%)	=L45*(100/L21)*(L20/(L20-1))		
	Pi (%)	=L15*(L46/100)		

Values of k for Use in Equation for Computing Diameter of Particles

Temperature	**Values of k**								
	Relative Density of Material Particles								
	2.45	**2.5**	**2.55**	**2.6**	**2.65**	**2.7**	**2.75**	**2.8**	**2.85**
16	0.0153	0.01505	0.01481	0.01457	0.01435	0.01414	0.01394	0.01374	0.01356
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.01339	0.01321
19	0.01474	0.01449	0.01425	0.01403	0.01382	0.01361	0.01342	0.01323	0.01305
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307	0.01289
21	0.01456	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273
22	0.01438	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276	0.01258
23	0.01421	0.01381	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261	0.01243
24	0.01404	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246	0.01229
25	0.01388	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215
26	0.01372	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.01218	0.01201
27	0.01357	0.01319	0.01297	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188
28	0.01342	0.01304	0.01283	0.01264	0.01244	0.01225	0.01208	0.01191	0.01175
29	0.01327	0.0129	0.01269	0.01249	0.0123	0.01212	0.01195	0.01178	0.01162
30	0.01312	0.01276	0.01256	0.01236	0.01217	0.01199	0.01182	0.01165	0.01149

Values of Effective Depth Based on the Hydrometer and Sedimentation Cylinder of Specified Size (Hydrometer 152H)

Reading	**Effective Depth**	**Reading**	**Effective Depth**	**Reading**	**Effective Depth**	**Reading**	**Effective Depth**
0	16.3	**16**	13.7	**32**	11.1	**48**	8.4
1	16.1	**17**	13.5	**33**	10.9	**49**	8.3
2	16	**18**	13.3	**34**	10.7	**50**	8.1
3	15.8	**19**	13.2	**35**	10.6	**51**	7.9
4	15.6	**20**	13	**36**	10.4	**52**	7.8
5	15.5	**21**	12.9	**37**	10.2	**53**	7.6
6	15.3	**22**	12.7	**38**	10.1	**54**	7.4
7	15.2	**23**	12.5	**39**	9.9	**55**	7.3
8	15	**24**	12.4	**40**	9.7	**56**	7.1
9	14.8	**25**	12.2	**41**	9.6	**57**	7
10	14.7	**26**	12	**42**	9.4	**58**	6.8
11	14.5	**27**	11.9	**43**	9.2	**59**	6.6
12	14.3	**28**	11.7	**44**	9.4	**60**	6.5
13	14.2	**29**	11.5	**45**	8.9		
14	14	**30**	11.4	**46**	8.8		
15	13.8	**31**	11.2	**47**	8.6		

Liquid Limit			
Method	Flow Curve		
	=IFS(B15="One Point","A (22 - 28 Taps)",B15="Two Point","A (20 - 24 Taps)",B15="Flow Curve","A (15 - 22 Taps)")	=IFS(B15="One Point","B (22 - 28 Taps)",B15="Two Point","B (26 - 30 Taps)",B15="Flow Curve","B (22- 28 Taps)")	=IFS(B15="One Point","A (18 - 22Taps)",B15="Two Point","",B15="Flow Curve","C (28 - 35 Taps)")
Tin Number	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],4,FALSE)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],5,FALSE)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],6,FALSE)
Number of Taps	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],7,FALSE)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],8,FALSE)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],9,FALSE)
Mass Tin + Wet (g)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],10,FALSE)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],11,FALSE)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],12,FALSE)
Mass Tin + Dry (g)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],13,FALSE)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],14,FALSE)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],15,FALSE)
Mass Tin (g)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],16,FALSE)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],17,FALSE)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],18,FALSE)
Mass Moisture (g)	=B19-B20	=C19-C20	=D19-D20
Mass Dry (g)	=B20-B21	=C20-C21	=D20-D21
% Moisture	=(B22/B23)*100	=(C22/C23)*100	=(D22/D23)*100
	=(B18/25)^0.12	=(C18/25)^0.12	=(D18/25)^0.12
	=B24*(B18/25)^0.12	=C24*(C18/25)^0.12	=D24*(D18/25)^0.12
Final Liquid Limit	=IFS(B15="One Point",AVERAGE(B26:D26),B15="Two Point",AVERAGE(B26:C26),B15="Flow Curve",SLOPE(B24:D24,B18:D18)*25+INTERCEPT(B24:D24,B18:D18))		

=SLOPE(B24:D24,B18:D18)*25+INTERCEPT(B24:D24,B18:D18) - Used for graph

Plastic Limit		
Tin Number	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],19,FALSE)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],20,FALSE)
Mass Tin + Wet (g)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],21,FALSE)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],22,FALSE)
Mass Tin + Dry (g)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],23,FALSE)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],24,FALSE)
Mass Tin (g)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],25,FALSE)	=VLOOKUP($B$9,E1_Atterberg_Limits_TBL[#All],26,FALSE)
Mass Moisture (g)	=B30-B31	=C30-C31
Mass Dry (g)	=B31-B32	=C31-C32
% Moisture	=IFERROR(100*(B33/B34),"")	=IFERROR(100*(C33/C34),"")

L_L (%)	=B27
P_L (%)	=AVERAGE(B35:C35)
P_i (%)	=B38-B39
Linear Shrinkage	
f	=0.533/(1-0.008*B18)
q	=VLOOKUP(B9,E2_Linear_Shrinkage_TBL[#All],4,FALSE)
L_S	=B42*B43

Specimen Sample A	
V_{W1}(mL) (Water measured into the sprinkler bottle)	=VLOOKUP($B$9,G1_OMC_MDD_TBL[#All],4,FALSE)
V_{WR} (mL) (Water remaining in the sprinkler bottle)	=VLOOKUP($B$9,G1_OMC_MDD_TBL[#All],5,FALSE)
V_{WA1} (mL) (Initial volume of water added to specimen sample)	=B15-B16
M_{WA1} (g) (Initial mass of water added to specimen sample A)	=B17
W_{A1} (%) (Moisture content of specimen sample A close to the OMC)	=100*(B18/F28)
W_{AEST} (Rounded % of WA1)	=ROUND(B19,0)
W_{A} (difference in WA1 and WAEST)	=B20-B19
M_{WA} (g)	=(B21*F28)/100
V_{WA} (mL)	=B22
V_{WA} (mL)	=B18+B23
M_{SWA} (g) (Wet mass of compacted specimen)	=VLOOKUP($B$9,G1_OMC_MDD_TBL[#All],6,FALSE)
M_{WA} (g) (Mass of the water added to specimen sample a)	=B24
W_{AEST} (%) (Estimated moisture content of specimen A)	=100*(B26/F28)
$D_{DA.EST}$ (kg/m3) (Estimated dry density of specimen A)	=(B25*F29)/(100+B20)

Specimen Sample B	
P_{WINC} (%) (Percentage water increment selected)	=VLOOKUP($B$9,G1_OMC_MDD_TBL[#All],7,FALSE)
V_{WA} (Volume of water added to specimen sample A)	=B24
M_{WINC} (g) (Mass water increment)	=(F28*D15)/100
V_{WINC} (mL) (Volume water increment)	=D17
V_{WB} (Volume of water to be added to specimen sample B)	=D16+D18
M_{WB} (g) (Mass of water added to specimen sample B)	=D19
M_{SWB} (g) (Wet mass of compacted specimen)	=VLOOKUP($B$9,G1_OMC_MDD_TBL[#All],8,FALSE)
$W_{B.EST}$ (%) (Estimated moisture content of specimen sample B)	=100*(D19/F28)
$D_{DB.EST}$ (kg/m3) (Estimated dry density of specimen sample B)	=(D21*43.2)/(100+D22)

Specimen Sample C	
V_{WC} (mL) (Volume of water to be added to specimen sample C)	=IF(B28<D23,D16+2*D18,D16-D18)
M_{SWC} (g) (Wet mass of compacted specimen)	=VLOOKUP($B$9,G1_OMC_MDD_TBL[#All],9,FALSE)
M_{WC} (g) (Mass of water added to specimen sample C)	=D25
$W_{C.EST}$ (%) (Estimated moisture content of specimen sample C)	=100*(D25/F28)
$D_{DC.EST}$ (kg/m3) (Estimated dry density of specimen sample C)	=(D26*F29)/(100+D28)

Specimen Sample D	
$W_{D.EST}$ (%) (Estimated moisture content of specimen sample D)	=VLOOKUP($B$9,G1_OMC_MDD_TBL[#All],10,FALSE)
M_{WD} (g) (Mass of water added to specimen sample D)	=F28*F15*0.01
V_{WD} (Volume of water to be added to specimen sample D)	=F16
M_{SWD} (g) (Wet mass of compacted specimen D)	=VLOOKUP($B$9,G1_OMC_MDD_TBL[#All],11,FALSE)
$D_{DD.EST}$ (kg/m3) (Estimated dry density of specimen sample D)	=(F18*F29)/(100+F15)

Specimen Sample E	
$W_{E.EST}$ (%) (Estimated moisture content of specimen sample E)	=VLOOKUP($B$9,G1_OMC_MDD_TBL[#All],12,FALSE)
MWE (g) (Mass of water added to specimen sample E)	=(F22*F28)/100
V_{WE} (Volume of water to be added to specimen sample E)	=F23
MSWE (g) (Wet mass of compacted specimen E)	=VLOOKUP($B$9,G1_OMC_MDD_TBL[#All],13,FALSE)
DDE.EST (kg/m3) (Estimated dry density of specimen sample E)	=(F25*F29)/(100+F22)

Input Values	
M_S	=VLOOKUP($B$9,G1_OMC_MDD_TBL[#All],14,FALSE)
F_M (Mould factor)	43.2

Results Summary				
Sample	**Mass of compacted soil (kg)**	**Density (kg/m3)**	**Dry density (kg/m3)**	**MC (%)**
A	=VLOOKUP(S32,G2_OMC_Readings_TBL[#All],4,FALSE)	=B33/0.0023045	=B28	**=B27**
B	=VLOOKUP(S33,G2_OMC_Readings_TBL[#All],4,FALSE)	=B34/0.0023045	=D23	**=D22**
C	=VLOOKUP(S34,G2_OMC_Readings_TBL[#All],4,FALSE)	=B35/0.0023045	=D29	**=D28**
D	=VLOOKUP(S35,G2_OMC_Readings_TBL[#All],4,FALSE)	=B36/0.0023045	=F19	**=F15**
E	=VLOOKUP(S36,G2_OMC_Readings_TBL[#All],4,FALSE)	=B37/0.0023045	=F26	**=F22**

Results	
Optimum Moisture Content	=Q33
Maximum Dry Density	=R34

External Calculations

									x	y
=E33	=D33		=SORT(E33:E37)	=VLOOKUP(K33,$H$33:$I$37,2,FALSE)		=SLOPE(L33:L35,K33:K35)	=INTERCEPT(L33:L35,K33:K35)		=(O34-O33)/(N33-N34)	0
=E34	=D34			=VLOOKUP(K34,$H$33:$I$37,2,FALSE)		=SLOPE(L35:L37,K35:K37)	=INTERCEPT(L35:L37,K35:K37)		0	=N33*Q33+O33
=E35	=D35			=VLOOKUP(K35,$H$33:$I$37,2,FALSE)						
=E36	=D36			=VLOOKUP(K36,$H$33:$I$37,2,FALSE)						
=E37	=D37			=VLOOKUP(K37,$H$33:$I$37,2,FALSE)						

California Bearing Ratio

Moisture Content		
Mass of Wet Soil + Container (g)	=VLOOKUP(C9;H1_CBR_TBL[#All];8;FALSE)	=VLOOKUP(D9;H1_CBR_TBL[#All];9;FALSE)
Mass of Dry Soil + Container (g)	=VLOOKUP(C10;H1_CBR_TBL[#All];10;FALSE)	=VLOOKUP(D10;H1_CBR_TBL[#All];11;FALSE)
Mass of Container (g)	=VLOOKUP(C11;H1_CBR_TBL[#All];12;FALSE)	=VLOOKUP(D11;H1_CBR_TBL[#All];13;FALSE)
Mass of Moisture (g)	=(K6-K7)	=(L6-L7)
Mass of Dry Soil (g)	=(K7-K8)	=(L7-L8)
Moisture Content (%)	=(K9/K10)*100	=(L9/L10)*100
Average Moisture Content (%)	=(K11+L11)/2	

Specimens					
A		B		C	
M_{SWA}	=VLOOKUP(C9;H1_CBR_TBL[#All];17;FALSE)	M_{SWB}	=VLOOKUP(C9;H1_CBR_TBL[#All];21;FALSE)	M_{SWC}	=VLOOKUP(C9;H1_CBR_TBL[#All];25;FALSE)
F_{MA}	=VLOOKUP(C9;H1_CBR_TBL[#All];14;FALSE)	F_{MB}	=B18	F_{MC}	=D18
D_{DA}	=((B17*B18)/(100+K12))	D_{DB}	=((D17*D18)/(100+K12))	D_{DC}	=((F17*F18)/(100+K12))
C_{RA}	=100*(B19/B19)	C_{RB}	=100*(D19/B19)	C_{RC}	=100*(F19/B19)
R_{FA}	=VLOOKUP(C9;H1_CBR_TBL[#All];20;FALSE)	R_{FB}	=VLOOKUP(C9;H1_CBR_TBL[#All];23;FALSE)	R_{FC}	=VLOOKUP(C9;H1_CBR_TBL[#All];27;FALSE)
R_{1A}	=VLOOKUP(C9;H1_CBR_TBL[#All];21;FALSE)	R_{1B}	=VLOOKUP(C9;H1_CBR_TBL[#All];24;FALSE)	R_{1C}	=VLOOKUP(C9;H1_CBR_TBL[#All];28;FALSE)
S_A	=100*(B21-B22)/127	S_B	=100*(D21-D22)/127	S_C	=100*(F21-F22)/127
M_{SSA}	=VLOOKUP(C9;H1_CBR_TBL[#All];17;FALSE)	M_{SSB}	4850	M_{SSC}	4710
W_{SSA}	=(((B24)/B17)*(100+K12)-100)	W_{SSB}	=(((D24)/D17)*(100+K12)-100)	W_{SSC}	=(((F24)/F17)*(100+K12)-100)

Specimens					
A		B		C	
Penetration Depth	Applied Force	Penetration Depth	Applied Force	Penetration Depth	Applied Force
=VLOOKUP(G30;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(G30;H2_CBR_Tests_TBL[#All];6;FALSE)	=VLOOKUP(H30;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(H30;H2_CBR_Tests_TBL[#All];6;FALSE)	=VLOOKUP(I30;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(I30;H2_CBR_Tests_TBL[#All];6;FALSE)
=VLOOKUP(G31;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(G31;H2_CBR_Tests_TBL[#All];6;FALSE)	=VLOOKUP(H31;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(H31;H2_CBR_Tests_TBL[#All];6;FALSE)	=VLOOKUP(I31;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(I31;H2_CBR_Tests_TBL[#All];6;FALSE)
=VLOOKUP(G32;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(G32;H2_CBR_Tests_TBL[#All];6;FALSE)	=VLOOKUP(H32;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(H32;H2_CBR_Tests_TBL[#All];6;FALSE)	=VLOOKUP(I32;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(I32;H2_CBR_Tests_TBL[#All];6;FALSE)
=VLOOKUP(G33;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(G33;H2_CBR_Tests_TBL[#All];6;FALSE)	=VLOOKUP(H33;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(H33;H2_CBR_Tests_TBL[#All];6;FALSE)	=VLOOKUP(I33;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(I33;H2_CBR_Tests_TBL[#All];6;FALSE)
=VLOOKUP(G34;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(G34;H2_CBR_Tests_TBL[#All];6;FALSE)	=VLOOKUP(H34;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(H34;H2_CBR_Tests_TBL[#All];6;FALSE)	=VLOOKUP(I34;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(I34;H2_CBR_Tests_TBL[#All];6;FALSE)
=VLOOKUP(G35;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(G35;H2_CBR_Tests_TBL[#All];6;FALSE)	=VLOOKUP(H35;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(H35;H2_CBR_Tests_TBL[#All];6;FALSE)	=VLOOKUP(I35;H2_CBR_Tests_TBL[#All];5;FALSE)	=VLOOKUP(I35;H2_CBR_Tests_TBL[#All];6;FALSE)

One Dimensional Consolidation

Initial & Final Readings		
	Initial Specimen	Final Specimen
Container Label	=VLOOKUP(B8;I1_Consolidation_TBL[#All];14;FALSE)	=VLOOKUP(C8;I1_Consolidation_TBL[#All];22;FALSE)
Weight Of Wet Soil + Container (g)	=VLOOKUP(B9;I1_Consolidation_TBL[#All];15;FALSE)	=VLOOKUP(B9;I1_Consolidation_TBL[#All];23;FALSE)
Weight Of Dry Soil + Container (g)	=VLOOKUP(B9;I1_Consolidation_TBL[#All];16;FALSE)	=VLOOKUP(B9;I1_Consolidation_TBL[#All];24;FALSE)
Weight Of Container (g)	=VLOOKUP(B9;I1_Consolidation_TBL[#All];17;FALSE)	=VLOOKUP(B9;I1_Consolidation_TBL[#All];25;FALSE)
Wet soil (g)	=F8-F10	=G8-G10
Dry soil (g)	=F9-F10	=G9-G10
Water (g)	=F11-F12	=G11-G12
Moisture Content (%)	=F13/F11	=IFERROR(@MoistureContent(G8;G9;G10);"")
Ring Weight	=VLOOKUP(B9;I1_Consolidation_TBL[#All];4;FALSE)	
Moist Weight + Ring Weight	=VLOOKUP(B9;I1_Consolidation_TBL[#All];16;FALSE)	=VLOOKUP(B9;I1_Consolidation_TBL[#All];16;FALSE)
Dry Mass (g)	=IFERROR((F16-F15)/(1+F14/100);"")	=IFERROR((G16-F15)/(1+G14/100);"")
Dry Density (g/m^3)	=F17/(B19*0,001)	=IFERROR(@DryDensityBS(G21;G14);"")

Summary										
Sequence	Load Sequence (Kpa)	Cumulative Change in Height (mm)	Specimen Height (mm)	Voids Height (mm)	Vertical Strain (%)	Void Ratio (mm)	T90 Fitting Time (Hours)	T50 Fitting Time (Hr)	T90 CV (mm²/Min)	T50 CV (mm²/Min)
0	=VLOOKUP(N26;I2_Axial_Stress_Time_Heights_TBL[#All];7;FALSE)	=VLOOKUP(N26;I2_Axial_Stress_Time_Heights_TBL[#All];8;FALSE)	=VLOOKUP(N26;I2_Axial_Stress_Time_Heights_TBL[#All];9;FALSE)	=VLOOKUP(N26;I2_Axial_Stress_Time_Heights_TBL[#All];10;FALSE)	=VLOOKUP(N26;I2_Axial_Stress_Time_Heights_TBL[#All];11;FALSE)	=VLOOKUP(N26;I2_Axial_Stress_Time_Heights_TBL[#All];12;FALSE)	=VLOOKUP(N26;I2_Axial_Stress_Time_Heights_TBL[#All];13;FALSE)	=VLOOKUP(N26;I2_Axial_Stress_Time_Heights_TBL[#All];14;FALSE)	=VLOOKUP(N26;I2_Axial_Stress_Time_Heights_TBL[#All];15;FALSE)	=VLOOKUP(N26;I2_Axial_Stress_Time_Heights_TBL[#All];16;FALSE)
1	=VLOOKUP(N27;I2_Axial_Stress_Time_Heights_TBL[#All];7;FALSE)	=VLOOKUP(N27;I2_Axial_Stress_Time_Heights_TBL[#All];8;FALSE)	=VLOOKUP(N27;I2_Axial_Stress_Time_Heights_TBL[#All];9;FALSE)	=VLOOKUP(N27;I2_Axial_Stress_Time_Heights_TBL[#All];10;FALSE)	=VLOOKUP(N27;I2_Axial_Stress_Time_Heights_TBL[#All];11;FALSE)	=VLOOKUP(N27;I2_Axial_Stress_Time_Heights_TBL[#All];12;FALSE)	=VLOOKUP(N27;I2_Axial_Stress_Time_Heights_TBL[#All];13;FALSE)	=VLOOKUP(N27;I2_Axial_Stress_Time_Heights_TBL[#All];14;FALSE)	=VLOOKUP(N27;I2_Axial_Stress_Time_Heights_TBL[#All];15;FALSE)	=VLOOKUP(N27;I2_Axial_Stress_Time_Heights_TBL[#All];16;FALSE)

="Sequence "&A37						
Reading	Elapsed Time	Load	Displacement	Settlement	Strain	Void Ratio
1	=IFERROR(VLOOKUP(A41;$Y$3:$AG$56;2;FALSE);"")	=IFERROR(VLOOKUP(A41;$Y$3:$AG$56;4;FALSE);"")	=IFERROR(VLOOKUP(A41;$Y$3:$AG$56;4;FALSE);"")	=IFERROR(F40+E40-E41;"")	=IFERROR(100*(F41/$B$16);"")	=IFERROR($F$20-(F41/$B$20);"")
2	=IFERROR(VLOOKUP(A42;$Y$3:$AG$56;2;FALSE);"")	=IFERROR(VLOOKUP(A42;$Y$3:$AG$56;4;FALSE);"")	=IFERROR(VLOOKUP(A42;$Y$3:$AG$56;4;FALSE);"")	=IFERROR(F41+E41-E42;"")	=IFERROR(100*(F42/$B$16);"")	=IFERROR($F$20-(F42/$B$20);"")
3	=IFERROR(VLOOKUP(A43;$Y$3:$AG$56;2;FALSE);"")	=IFERROR(VLOOKUP(A43;$Y$3:$AG$56;4;FALSE);"")	=IFERROR(VLOOKUP(A43;$Y$3:$AG$56;4;FALSE);"")	=IFERROR(F42+E42-E43;"")	=IFERROR(100*(F43/$B$16);"")	=IFERROR($F$20-(F43/$B$20);"")
4	=IFERROR(VLOOKUP(A44;$Y$3:$AG$56;2;FALSE);"")	=IFERROR(VLOOKUP(A44;$Y$3:$AG$56;4;FALSE);"")	=IFERROR(VLOOKUP(A44;$Y$3:$AG$56;4;FALSE);"")	=IFERROR(F43+E43-E44;"")	=IFERROR(100*(F44/$B$16);"")	=IFERROR($F$20-(F44/$B$20);"")

Direct Shear

Information	SPECIMEN		
	1	2	3
Test Procedure	=VLOOKUP(C9;H1_CBR_TBL[#All];3;FALSE)	Direct Shear	Direct Shear
Sample Type	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];4;FALSE)	Remoulded	Remoulded
Specific Gravity	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];5;FALSE)	2,72000002861022	2,72000002861022
Specific Gravity Method	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];6;FALSE)	ASSUMED	ASSUMED

Initial Parameters	SPECIMEN		
	1	2	3
Test Temperature (°C)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];7;FALSE)	26	24
Sample Shape	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];8;FALSE)	SQUARE	SQUARE
Height (mm)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];9;FALSE)	19,8500003814697	19,9099998474121
Diameter and Length (mm)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];10;FALSE)	51,9099998474121	59,9099998474121
Area (cm²)	=IF(B23="SQUARE";B25^2;IF(B23="Round";PI()*(B25/2)^2;""))/100	=IF(C23="SQUARE";C25^2;IF(C23="Round";PI()*(C25/2)^2;""))/100	=IF(D23="SQUARE";D25^2;IF(D23="Round";PI()*(D25/2)^2;""))/100

Volume (cm²)	=B26*B24/10	=C26*C24/10	=D26*D24/10
Weight of Container (g)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];11;FALSE)	16,6399993896484	16,6299991607666
Weight of Wet Soil + Container (g)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];12;FALSE)	32,1599998474121	42,849998474121
Weight of Dry Soil + Container (g)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];13;FALSE)	29,9699993133544	39,2900009155273
Moisture Content	=((B29-B28)-(B30-B28))/(B30-B28)	16,4291114807128	15,7104911804199
Wet Weight of Ring + Soil (g)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];14;FALSE)	227,639999389648	232,289993286132
Weight of Ring (g)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];15;FALSE)	89,2099990844726	89,2600021362304
Moist Weight (g)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];16;FALSE)	138,429992675781	143,029998779296
Dry Weight (g)	=E19/(1+E31)	=F19/(1+F31)	=G19/(1+G31)
Wet Density (g/cm³)	=E22/E26	=F22/F26	=G22/G26
Saturation (%)	=VLOOKUP(B12;M2_Triaxial Readings (Sat)_TBL[#All];22;FALSE)	=VLOOKUP(C12;M2_Triaxial Readings (Sat)_TBL[#All];22;FALSE)	=VLOOKUP(D12;M2_Triaxial Readings (Sat)_TBL[#All];22;FALSE)
Void Ratio	=VLOOKUP(B9;M2_Triaxial Readings (Sat)_TBL[#All];23;FALSE)	=VLOOKUP(C9;M2_Triaxial Readings (Sat)_TBL[#All];23;FALSE)	=VLOOKUP(D9;M2_Triaxial Readings (Sat)_TBL[#All];23;FALSE)
Porosity (%)	=(E19*E27)/E31	=(F19*F27)/F31	=(G19*G27)/G31

Consolidation Parameters	SPECIMEN		
	1	2	3
Initial Height (mm)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];22;FALSE)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];22;FALSE)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];22;FALSE)
Final Height (mm)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];23;FALSE)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];23;FALSE)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];23;FALSE)
Height (mm)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];24;FALSE)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];24;FALSE)	=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];24;FALSE)

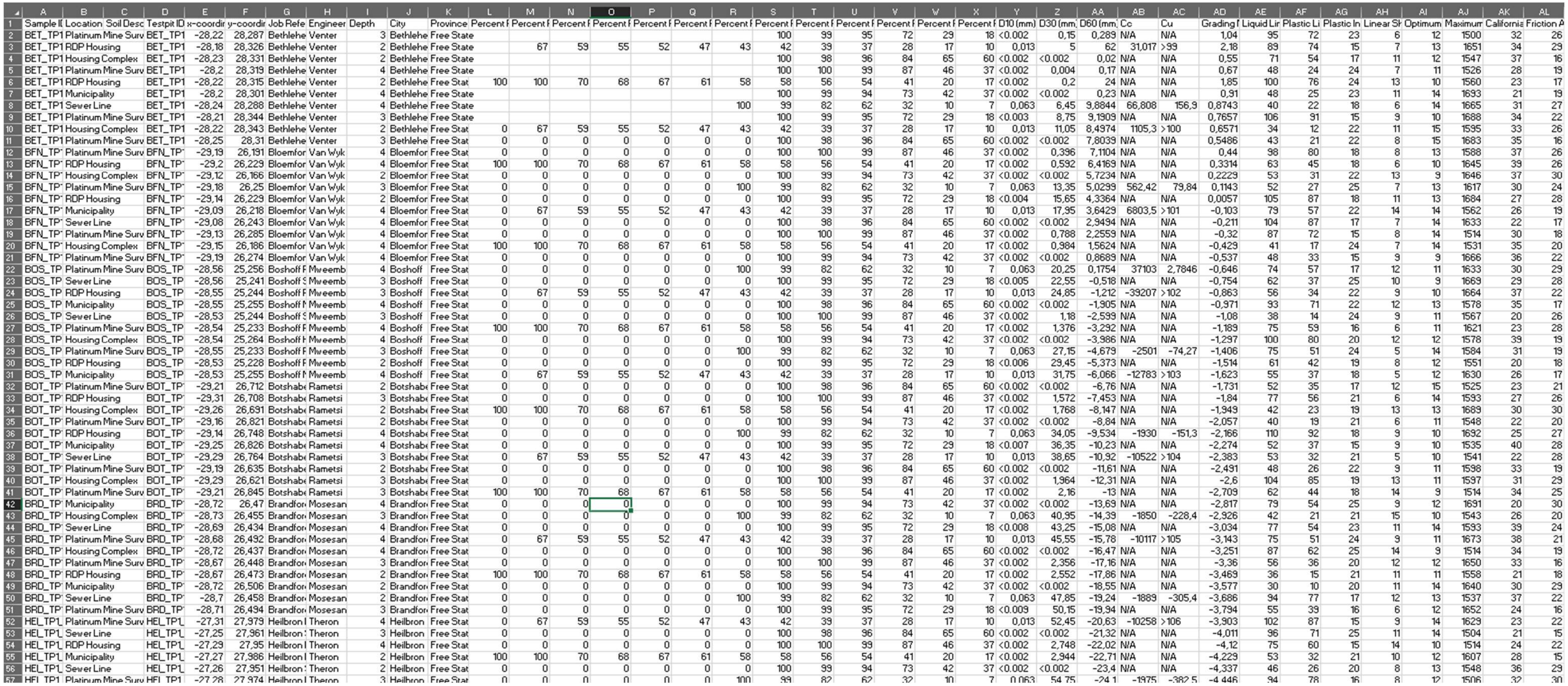
<table>
<tr><th rowspan="2">Final Parameters</th><th colspan="3">SPECIMEN</th></tr>
<tr><th>1</th><th>2</th><th>3</th></tr>
<tr><td>Final Moisture Content (%)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];25;FALSE)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];25;FALSE)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];25;FALSE)</td></tr>
<tr><td>Wet Weight of Ring + Soil (g)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];26;FALSE)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];26;FALSE)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];26;FALSE)</td></tr>
<tr><td>Moist Weight (g)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];27;FALSE)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];27;FALSE)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];27;FALSE)</td></tr>
<tr><td>Dry Weight (g)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];28;FALSE)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];28;FALSE)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];28;FALSE)</td></tr>
<tr><td>Wet Density (g/cm³)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];29;FALSE)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];29;FALSE)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];29;FALSE)</td></tr>
<tr><td>Saturation (%)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];30;FALSE)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];30;FALSE)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];30;FALSE)</td></tr>
<tr><td>Void Ratio</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];31;FALSE)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];31;FALSE)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];31;FALSE)</td></tr>
<tr><td>Porosity (%)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];32;FALSE)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];32;FALSE)</td><td>=VLOOKUP(C9;K1_DIRECT SHEAR TEST_TBL[#All];32;FALSE)</td></tr>
</table>

Triaxial

Information	SPECIMEN		
	1	2	3
Test Procedure	=VLOOKUP(B9;M1_Triaxial_TBL[#All];3;FALSE)	=VLOOKUP(C9;M1_Triaxial_TBL[#All];3;FALSE)	=VLOOKUP(D9;M1_Triaxial_TBL[#All];3;FALSE)
Sample Type	=VLOOKUP(B9;M1_Triaxial_TBL[#All];4;FALSE)	=VLOOKUP(C9;M1_Triaxial_TBL[#All];4;FALSE)	=VLOOKUP(D9;M1_Triaxial_TBL[#All];4;FALSE)
Specific Gravity	=VLOOKUP(B9;M1_Triaxial_TBL[#All];7;FALSE)	=VLOOKUP(C9;M1_Triaxial_TBL[#All];7;FALSE)	=VLOOKUP(D9;M1_Triaxial_TBL[#All];7;FALSE)
Initial Parameters	SPECIMEN		
	1	2	3
Mass of Solid (g)	=VLOOKUP(B9;M2_Triaxial Readings (Sat)_TBL[#All];;FALSE)	=VLOOKUP(C9;M2_Triaxial Readings (Sat)_TBL[#All];;FALSE)	=VLOOKUP(D9;M2_Triaxial Readings (Sat)_TBL[#All];;FALSE)
Height (mm)	=VLOOKUP(B9;M2_Triaxial Readings (Sat)_TBL[#All];12;FALSE)	=VLOOKUP(C9;M2_Triaxial Readings (Sat)_TBL[#All];12;FALSE)	=VLOOKUP(D9;M2_Triaxial Readings (Sat)_TBL[#All];12;FALSE)
Diameter (mm)	=VLOOKUP(B9;M2_Triaxial Readings (Sat)_TBL[#All];13;FALSE)	=VLOOKUP(C9;M2_Triaxial Readings (Sat)_TBL[#All];13;FALSE)	=VLOOKUP(D9;M2_Triaxial Readings (Sat)_TBL[#All];13;FALSE)
Area (cm²)	=(PI()*((E24/2)^2))/100	=(PI()*((F24/2)^2))/100	=(PI()*((G24/2)^2))/100
Volume (cm³)	=E25*(E23/10)	=F25*(F23/10)	=G25*(G23/10)
Moisture Content (%)	=VLOOKUP(B9;M2_Triaxial Readings (Sat)_TBL[#All];18;FALSE)	=VLOOKUP(C9;M2_Triaxial Readings (Sat)_TBL[#All];18;FALSE)	=VLOOKUP(D9;M2_Triaxial Readings (Sat)_TBL[#All];18;FALSE)
Dry Density (g/cm³)	=E19/(1+E31)	=F19/(1+F31)	=G19/(1+G31)
Wet Density (g/cm³)	=E22/E26	=F22/F26	=G22/G26
Saturation (%)	=VLOOKUP(B12;M2_Triaxial Readings (Sat)_TBL[#All];22;FALSE)	=VLOOKUP(C12;M2_Triaxial Readings (Sat)_TBL[#All];22;FALSE)	=VLOOKUP(D12;M2_Triaxial Readings (Sat)_TBL[#All];22;FALSE)
Void Ratio	=VLOOKUP(B9;M2_Triaxial Readings (Sat)_TBL[#All];23;FALSE)	=VLOOKUP(C9;M2_Triaxial Readings (Sat)_TBL[#All];23;FALSE)	=VLOOKUP(D9;M2_Triaxial Readings (Sat)_TBL[#All];23;FALSE)
Degree of Saturation (%)	=(E19*E27)/E31	=(F19*F27)/F31	=(G19*G27)/G31

Saturation Parameters	SPECIMEN		
	1	2	3
Cell Pressure (kPa)	=VLOOKUP(B9;M2_Triaxial Readings (Sat)_TBL[#All];3;FALSE)	=VLOOKUP(C9;M2_Triaxial Readings (Sat)_TBL[#All];3;FALSE)	=VLOOKUP(D9;M2_Triaxial Readings (Sat)_TBL[#All];3;FALSE)
Back Pressure (kPa)	=VLOOKUP(B9;M2_Triaxial Readings (Sat)_TBL[#All];4;FALSE)	=VLOOKUP(C9;M2_Triaxial Readings (Sat)_TBL[#All];4;FALSE)	=VLOOKUP(D9;M2_Triaxial Readings (Sat)_TBL[#All];4;FALSE)
B Value	=VLOOKUP(B9;M2_Triaxial Readings (Sat)_TBL[#All];5;FALSE)	=VLOOKUP(C9;M2_Triaxial Readings (Sat)_TBL[#All];5;FALSE)	=VLOOKUP(D9;M2_Triaxial Readings (Sat)_TBL[#All];5;FALSE)
Consolidation Parameters	SPECIMEN		
	1	2	3
Cell Pressure (kPa)	=VLOOKUP(B9;M3_Triaxial Readings (Con)_TBL[#All];3;FALSE)	=VLOOKUP(C9;M3_Triaxial Readings (Con)_TBL[#All];3;FALSE)	=VLOOKUP(D9;M3_Triaxial Readings (Con)_TBL[#All];3;FALSE)
Back Pressure (kPa)	=VLOOKUP(B9;M3_Triaxial Readings (Con)_TBL[#All];4;FALSE)	=VLOOKUP(C9;M3_Triaxial Readings (Con)_TBL[#All];4;FALSE)	=VLOOKUP(D9;M3_Triaxial Readings (Con)_TBL[#All];4;FALSE)
Pore Pressure (Initial) (kPa)	=VLOOKUP(B9;M3_Triaxial Readings (Con)_TBL[#All];5;FALSE)	=VLOOKUP(C9;M3_Triaxial Readings (Con)_TBL[#All];5;FALSE)	=VLOOKUP(D9;M3_Triaxial Readings (Con)_TBL[#All];5;FALSE)
Pore Pressure (Final) (kPa)	=VLOOKUP(B9;M3_Triaxial Readings (Con)_TBL[#All];6;FALSE)	=VLOOKUP(C9;M3_Triaxial Readings (Con)_TBL[#All];6;FALSE)	=VLOOKUP(D9;M3_Triaxial Readings (Con)_TBL[#All];6;FALSE)
Volumetric Strain (%)	=VLOOKUP(B9;M3_Triaxial Readings (Con)_TBL[#All];7;FALSE)	=VLOOKUP(C9;M3_Triaxial Readings (Con)_TBL[#All];7;FALSE)	=VLOOKUP(D9;M3_Triaxial Readings (Con)_TBL[#All];7;FALSE)
Effective Stress at beginning of shear (kPa)	=VLOOKUP(B9;M3_Triaxial Readings (Con)_TBL[#All];8;FALSE)	=VLOOKUP(C9;M3_Triaxial Readings (Con)_TBL[#All];8;FALSE)	=VLOOKUP(D9;M3_Triaxial Readings (Con)_TBL[#All];8;FALSE)
Final Parameters	SPECIMEN		
	1	2	3
Moisture Content (%)	=VLOOKUP(B9;M1_Triaxial_TBL[#All];3;FALSE)	=VLOOKUP(C9;M1_Triaxial_TBL[#All];3;FALSE)	=VLOOKUP(D9;M1_Triaxial_TBL[#All];3;FALSE)
Dry Density (g/cm³)	=VLOOKUP(B9;M1_Triaxial_TBL[#All];4;FALSE)	=VLOOKUP(C9;M1_Triaxial_TBL[#All];4;FALSE)	=VLOOKUP(D9;M1_Triaxial_TBL[#All];4;FALSE)
Void Ratio (Assumed Sr = 1)	=VLOOKUP(B9;M1_Triaxial_TBL[#All];5;FALSE)	=VLOOKUP(C9;M1_Triaxial_TBL[#All];5;FALSE)	=VLOOKUP(D9;M1_Triaxial_TBL[#All];5;FALSE)

Example of Generated CSV File



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL
1	Sample I	Location	Soil Desc	Testpit ID	x-coordi	y-coordi	Job Refe	Engineer	Depth	City	Province	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	D10 (mm)	D30 (mm	D60 (mm	Cc	Cu	Grading	Liquid Li	Plastic Li	Plastic In	Linear S	Optimum	Maximu	California	Friction
2	BET_TP1	Platinum Mine Surv		BET_TP1	-28,22	28,287	Bethlehe	Venter	3	Bethlehe	Free State								100	99	95	72	29	18	<0.002	0,15	0,289	N/A	N/A	1,04	95	72	23	6	12	1500	32	26
3	BET_TP1	RDP Housing		BET_TP1	-28,18	28,326	Bethlehe	Venter	2	Bethlehe	Free State		67	59	55	52	47	43	42	39	37	28	17	10	0,013	5	62	31,017	>99	2,18	89	74	15	7	13	1651	34	29
4	BET_TP1	Housing Complex		BET_TP1	-28,23	28,331	Bethlehe	Venter	2	Bethlehe	Free State								100	98	96	84	65	60	<0.002	<0.002	0,02	N/A	N/A	0,55	71	54	17	11	12	1547	37	16
5	BET_TP1	Platinum Mine Surv		BET_TP1	-28,2	28,319	Bethlehe	Venter	4	Bethlehe	Free State								100	100	99	87	46	37	<0.002	0,004	0,17	N/A	N/A	0,67	48	24	24	7	11	1526	28	19
6	BET_TP1	RDP Housing		BET_TP1	-28,22	28,315	Bethlehe	Venter	2	Bethlehe	Free Stat	100	100	70	68	67	61	58	58	56	54	41	20	17	<0.002	0,2	24	N/A	N/A	1,85	100	76	24	13	10	1560	23	17
7	BET_TP1	Municipality		BET_TP1	-28,2	28,301	Bethlehe	Venter	4	Bethlehe	Free State								100	99	94	73	42	37	<0.002	<0.002	0,23	N/A	N/A	0,91	48	25	23	11	14	1693	21	19
8	BET_TP1	Sewer Line		BET_TP1	-28,24	28,288	Bethlehe	Venter	4	Bethlehe	Free State							100	99	82	62	32	10	7	0,063	6,45	9,8844	66,808	156,9	0,8743	40	22	18	6	14	1665	31	27
9	BET_TP1	Platinum Mine Surv		BET_TP1	-28,21	28,344	Bethlehe	Venter	3	Bethlehe	Free State								100	99	95	72	29	18	<0.003	8,75	9,1909	N/A	N/A	0,7657	106	91	15	9	10	1688	34	22
10	BET_TP1	Housing Complex		BET_TP1	-28,22	28,343	Bethlehe	Venter	2	Bethlehe	Free Stat	0	67	59	55	52	47	43	42	39	37	28	17	10	0,013	11,05	8,4974	1105,3	>100	0,6571	34	12	22	11	15	1595	33	26
11	BET_TP1	Platinum Mine Surv		BET_TP1	-28,25	28,31	Bethlehe	Venter	3	Bethlehe	Free Stat	0	0	0	0	0	0	0	100	98	96	84	65	60	<0.002	<0.002	7,8039	N/A	N/A	0,5486	43	21	22	8	15	1683	35	16
12	BFN_TP	Platinum Mine Surv		BFN_TP	-29,19	26,191	Bloemfor	Van Wyk	4	Bloemfor	Free Stat	0	0	0	0	0	0	0	100	100	99	87	46	37	<0.002	0,396	7,1104	N/A	N/A	0,44	98	80	18	8	13	1588	37	26
13	BFN_TP	RDP Housing		BFN_TP	-29,2	26,229	Bloemfor	Van Wyk	4	Bloemfor	Free Stat	100	100	70	68	67	61	58	58	56	54	41	20	17	<0.002	0,592	6,4169	N/A	N/A	0,3314	63	45	18	6	10	1645	39	26
14	BFN_TP	Housing Complex		BFN_TP	-29,12	26,166	Bloemfor	Van Wyk	2	Bloemfor	Free Stat	0	0	0	0	0	0	0	100	99	94	73	42	37	<0.002	<0.002	5,7234	N/A	N/A	0,2229	53	31	22	13	9	1646	37	30
15	BFN_TP	Platinum Mine Surv		BFN_TP	-29,18	26,25	Bloemfor	Van Wyk	3	Bloemfor	Free Stat	0	0	0	0	0	0	100	99	82	62	32	10	7	0,063	13,35	5,0299	562,42	79,84	0,1143	52	27	25	7	13	1617	30	24
16	BFN_TP	RDP Housing		BFN_TP	-29,14	26,229	Bloemfor	Van Wyk	2	Bloemfor	Free Stat	0	0	0	0	0	0	0	100	99	95	72	29	18	<0.004	15,65	4,3364	N/A	N/A	0,0057	105	87	18	11	13	1684	27	28
17	BFN_TP	Municipality		BFN_TP	-29,09	26,218	Bloemfor	Van Wyk	4	Bloemfor	Free Stat	0	67	59	55	52	47	43	42	39	37	28	17	10	0,013	17,95	3,6429	6803,5	>101	-0,103	79	57	22	14	14	1562	26	19
18	BFN_TP	Sewer Line		BFN_TP	-29,08	26,243	Bloemfor	Van Wyk	4	Bloemfor	Free Stat	0	0	0	0	0	0	0	100	98	96	84	65	60	<0.002	<0.002	2,9494	N/A	N/A	-0,211	104	87	17	7	14	1633	22	17
19	BFN_TP	Platinum Mine Surv		BFN_TP	-29,13	26,285	Bloemfor	Van Wyk	4	Bloemfor	Free Stat	0	0	0	0	0	0	0	100	100	99	87	46	37	<0.002	0,788	2,2559	N/A	N/A	-0,32	87	72	15	8	14	1514	30	18
20	BFN_TP	Housing Complex		BFN_TP	-29,15	26,186	Bloemfor	Van Wyk	4	Bloemfor	Free Stat	100	100	70	68	67	61	58	58	56	54	41	20	17	<0.002	0,984	1,5624	N/A	N/A	-0,429	41	17	24	7	14	1531	35	20
21	BFN_TP	Platinum Mine Surv		BFN_TP	-29,19	26,274	Bloemfor	Van Wyk	4	Bloemfor	Free Stat	0	0	0	0	0	0	0	100	99	94	73	42	37	<0.002	<0.002	0,8689	N/A	N/A	-0,537	48	33	15	9	9	1666	36	22
22	BOS_TP	Platinum Mine Surv		BOS_TP	-28,56	25,256	Boshoff F	Mweemb	4	Boshoff	Free Stat	0	0	0	0	0	0	100	99	82	62	32	10	7	0,063	20,25	0,1754	37103	2,7846	-0,646	74	57	17	12	11	1633	30	29
23	BOS_TP	Sewer Line		BOS_TP	-28,56	25,241	Boshoff S	Mweemb	3	Boshoff	Free Stat	0	0	0	0	0	0	0	100	99	95	72	29	18	<0.005	22,55	-0,518	N/A	N/A	-0,754	62	37	25	10	9	1669	29	28
24	BOS_TP	RDP Housing		BOS_TP	-28,55	25,244	Boshoff F	Mweemb	3	Boshoff	Free Stat	0	67	59	55	52	47	43	42	39	37	28	17	10	0,013	24,85	-1,212	-39207	>102	-0,863	56	34	22	9	10	1664	37	22
25	BOS_TP	Municipality		BOS_TP	-28,55	25,255	Boshoff N	Mweemb	4	Boshoff	Free Stat	0	0	0	0	0	0	0	100	98	96	84	65	60	<0.002	<0.002	-1,905	N/A	N/A	-0,971	93	71	22	12	13	1578	35	17
26	BOS_TP	Sewer Line		BOS_TP	-28,53	25,244	Boshoff S	Mweemb	3	Boshoff	Free Stat	0	0	0	0	0	0	0	100	100	99	87	46	37	<0.002	1,18	-2,599	N/A	N/A	-1,08	38	14	24	9	11	1567	20	26
27	BOS_TP	Platinum Mine Surv		BOS_TP	-28,54	25,233	Boshoff F	Mweemb	4	Boshoff	Free Stat	100	100	70	68	67	61	58	58	56	54	41	20	17	<0.002	1,376	-3,292	N/A	N/A	-1,189	75	59	16	6	11	1621	23	28
28	BOS_TP	Housing Complex		BOS_TP	-28,54	25,264	Boshoff H	Mweemb	4	Boshoff	Free Stat	0	0	0	0	0	0	0	100	99	94	73	42	37	<0.002	<0.002	-3,986	N/A	N/A	-1,297	100	80	20	12	12	1578	39	19
29	BOS_TP	Platinum Mine Surv		BOS_TP	-28,55	25,233	Boshoff F	Mweemb	3	Boshoff	Free Stat	0	0	0	0	0	0	100	99	82	62	32	10	7	0,063	27,15	-4,679	-2501	-74,27	-1,406	75	51	24	5	14	1584	31	19
30	BOS_TP	RDP Housing		BOS_TP	-28,53	25,228	Boshoff F	Mweemb	2	Boshoff	Free Stat	0	0	0	0	0	0	0	100	99	95	72	29	18	<0.006	29,45	-5,373	N/A	N/A	-1,514	61	42	19	8	12	1551	20	18
31	BOS_TP	Municipality		BOS_TP	-28,53	25,255	Boshoff N	Mweemb	4	Boshoff	Free Stat	0	67	59	55	52	47	43	42	39	37	28	17	10	0,013	31,75	-6,066	-12783	>103	-1,623	55	37	18	5	12	1630	26	17
32	BOT_TP	Platinum Mine Surv		BOT_TP	-29,21	26,712	Botshabe	Rametsi	2	Botshabe	Free Stat	0	0	0	0	0	0	0	100	98	96	84	65	60	<0.002	<0.002	-6,76	N/A	N/A	-1,731	52	35	17	12	15	1525	23	21
33	BOT_TP	RDP Housing		BOT_TP	-29,31	26,708	Botshabe	Rametsi	3	Botshabe	Free Stat	0	0	0	0	0	0	0	100	100	99	87	46	37	<0.002	1,572	-7,453	N/A	N/A	-1,84	77	56	21	6	14	1593	27	26
34	BOT_TP	Housing Complex		BOT_TP	-29,26	26,691	Botshabe	Rametsi	2	Botshabe	Free Stat	100	100	70	68	67	61	58	58	56	54	41	20	17	<0.002	1,768	-8,147	N/A	N/A	-1,949	42	23	19	13	13	1689	30	30
35	BOT_TP	Platinum Mine Surv		BOT_TP	-29,16	26,821	Botshabe	Rametsi	2	Botshabe	Free Stat	0	0	0	0	0	0	0	100	99	94	73	42	37	<0.002	<0.002	-8,84	N/A	N/A	-2,057	40	19	21	6	11	1548	22	20
36	BOT_TP	RDP Housing		BOT_TP	-29,14	26,748	Botshabe	Rametsi	4	Botshabe	Free Stat	0	0	0	0	0	0	100	99	82	62	32	10	7	0,063	34,05	-9,534	-1930	-151,3	-2,166	110	92	18	9	10	1692	25	27
37	BOT_TP	Municipality		BOT_TP	-29,25	26,826	Botshabe	Rametsi	4	Botshabe	Free Stat	0	0	0	0	0	0	0	100	99	95	72	29	18	<0.007	36,35	-10,23	N/A	N/A	-2,274	52	37	15	9	10	1535	40	28
38	BOT_TP	Sewer Line		BOT_TP	-29,29	26,764	Botshabe	Rametsi	3	Botshabe	Free Stat	0	67	59	55	52	47	43	42	39	37	28	17	10	0,013	38,65	-10,92	-10522	>104	-2,383	53	32	21	5	10	1541	22	28
39	BOT_TP	Platinum Mine Surv		BOT_TP	-29,19	26,635	Botshabe	Rametsi	2	Botshabe	Free Stat	0	0	0	0	0	0	0	100	98	96	84	65	60	<0.002	<0.002	-11,61	N/A	N/A	-2,491	48	26	22	9	11	1598	33	19
40	BOT_TP	Housing Complex		BOT_TP	-29,29	26,621	Botshabe	Rametsi	3	Botshabe	Free Stat	0	0	0	0	0	0	0	100	100	99	87	46	37	<0.002	1,964	-12,31	N/A	N/A	-2,6	104	85	19	13	11	1597	31	29
41	BOT_TP	Platinum Mine Surv		BOT_TP	-29,21	26,845	Botshabe	Rametsi	3	Botshabe	Free Stat	100	100	70	68	67	61	58	58	56	54	41	20	17	<0.002	2,16	-13	N/A	N/A	-2,709	62	44	18	14	9	1514	34	25
42	BRD_TP	Municipality		BRD_TP	-28,72	26,47	Brandfor	Mosesan	4	Brandfor	Free Stat	0	0	0	0	0	0	0	100	99	94	73	42	37	<0.002	<0.002	-13,69	N/A	N/A	-2,817	79	54	25	9	12	1691	20	30
43	BRD_TP	Housing Complex		BRD_TP	-28,73	26,455	Brandfor	Mosesan	3	Brandfor	Free Stat	0	0	0	0	0	0	100	99	82	62	32	10	7	0,063	40,95	-14,39	-1850	-228,4	-2,926	42	21	21	15	10	1543	26	20
44	BRD_TP	Sewer Line		BRD_TP	-28,69	26,434	Brandfor	Mosesan	4	Brandfor	Free Stat	0	0	0	0	0	0	0	100	99	95	72	29	18	<0.008	43,25	-15,08	N/A	N/A	-3,034	77	54	23	11	14	1593	39	24
45	BRD_TP	Platinum Mine Surv		BRD_TP	-28,68	26,492	Brandfor	Mosesan	4	Brandfor	Free Stat	0	67	59	55	52	47	43	42	39	37	28	17	10	0,013	45,55	-15,78	-10117	>105	-3,143	75	51	24	9	11	1673	38	21
46	BRD_TP	Housing Complex		BRD_TP	-28,72	26,437	Brandfor	Mosesan	4	Brandfor	Free Stat	0	0	0	0	0	0	0	100	98	96	84	65	60	<0.002	<0.002	-16,47	N/A	N/A	-3,251	87	62	25	14	9	1514	34	19
47	BRD_TP	Platinum Mine Surv		BRD_TP	-28,67	26,448	Brandfor	Mosesan	3	Brandfor	Free Stat	0	0	0	0	0	0	0	100	100	99	87	46	37	<0.002	2,356	-17,16	N/A	N/A	-3,36	56	36	20	12	12	1650	33	16
48	BRD_TP	RDP Housing		BRD_TP	-28,67	26,473	Brandfor	Mosesan	2	Brandfor	Free Stat	100	100	70	68	67	61	58	58	56	54	41	20	17	<0.002	2,552	-17,86	N/A	N/A	-3,469	36	15	21	11	11	1558	21	18
49	BRD_TP	Municipality		BRD_TP	-28,72	26,506	Brandfor	Mosesan	2	Brandfor	Free Stat	0	0	0	0	0	0	0	100	99	94	73	42	37	<0.002	<0.002	-18,55	N/A	N/A	-3,577	30	10	20	11	14	1640	30	29
50	BRD_TP	Sewer Line		BRD_TP	-28,7	26,458	Brandfor	Mosesan	2	Brandfor	Free Stat	0	0	0	0	0	0	100	99	82	62	32	10	7	0,063	47,85	-19,24	-1889	-305,4	-3,686	94	77	17	12	13	1537	37	22
51	BRD_TP	Platinum Mine Surv		BRD_TP	-28,71	26,494	Brandfor	Mosesan	3	Brandfor	Free Stat	0	0	0	0	0	0	0	100	99	95	72	29	18	<0.009	50,15	-19,94	N/A	N/A	-3,794	55	39	16	6	12	1652	24	16
52	HEL_TP1_	Platinum Mine Surv		HEL_TP1_	-27,31	27,979	Heilbron I	Theron	4	Heilbron	Free Stat	0	67	59	55	52	47	43	42	39	37	28	17	10	0,013	52,45	-20,63	-10258	>106	-3,903	102	87	15	9	14	1629	23	22
53	HEL_TP1_	Sewer Line		HEL_TP1_	-27,25	27,961	Heilbron S	Theron	3	Heilbron	Free Stat	0	0	0	0	0	0	0	100	98	96	84	65	60	<0.002	<0.002	-21,32	N/A	N/A	-4,011	96	71	25	11	14	1504	21	15
54	HEL_TP1_	RDP Housing		HEL_TP1_	-27,29	27,95	Heilbron I	Theron	4	Heilbron	Free Stat	0	0	0	0	0	0	0	100	100	99	87	46	37	<0.002	2,748	-22,02	N/A	N/A	-4,12	75	60	15	14	10	1514	24	22
55	HEL_TP1_	Municipality		HEL_TP1_	-27,27	27,986	Heilbron I	Theron	2	Heilbron	Free Stat	100	100	70	68	67	61	58	58	56	54	41	20	17	<0.002	2,944	-22,71	N/A	N/A	-4,229	53	32	21	10	12	1607	28	15
56	HEL_TP1_	Sewer Line		HEL_TP1_	-27,26	27,951	Heilbron S	Theron	2	Heilbron	Free Stat	0	0	0	0	0	0	0	100	99	94	73	42	37	<0.002	<0.002	-23,4	N/A	N/A	-4,337	46	26	20	8	13	1548	36	29
57	HEL_TP1	Platinum Mine Surv		HEL_TP1	-27,28	27,974	Heilbron I	Theron	3	Heilbron	Free Stat	0	0	0	0	0	0	100	99	82	62	32	10	7	0,063	54,75	-24,1	-1975	-382,5	-4,446	94	78	16	8	12	1506	32	30