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water & sanitation

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REPUBLIC OF SOUTH AFRICA

Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam (WP0485)

Geotechnical Investigations Report: Vol III Ebenhaeser Scheme

April 2021

Department of Water and Sanitation
Directorate: Water Resource Development Planning

POST FEASIBILITY BRIDGING STUDY FOR THE PROPOSED BULK CONVEYANCE INFRASTRUCTURE FROM THE RAISED CLANWILLIAM DAM

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Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam

GEOTECHNICAL INVESTIGATIONS REPORT. VOL III: EBENHAESER SCHEME

April 2021

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Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam

Reports produced as part of this project are indicated below.

Bold type indicates this report.

Report Index	Report Number	Report Title
1		Inception Report
2	P WMA 09/E10/00/0417/2	Capacity Building & Training Year 1
3	P WMA 09/E10/00/0417/3	Capacity Building & Training Year 2
4	P WMA 09/E10/00/0417/4	Water Requirements Assessment
5	P WMA 09/E10/00/0417/5	Distribution of Additional Available Water
6		Existing Infrastructure and Current Agricultural Development Sub-Report
7	P WMA 09/E10/00/0417/6	Existing Conveyance Infrastructure and Irrigated Land
8		Suitable Agricultural Areas and Land Ownership Report
9		Evaluation of Development Options Sub-Report
10	P WMA 09/E10/00/0417/10	Suitable Areas for Agricultural Development
11		Right Bank Canal Design Sub-Report
12		Conceptual Design Sub-Report
13		Environmental Screening Sub-Report
14		Jan Dissels and Ebenhaeser Schemes Design Sub-Report
15	P WMA 09/E10/00/0417/13	Feasibility Design
16	P WMA 09/E10/00/0417/7	Topographical Surveys
17	**P WMA 09/E10/00/0417/8**	Geotechnical Investigations. Vol I: Jan Dissels Scheme Geotechnical Investigations. Vol II: Right Bank Canal Scheme **Geotechnical Investigations. Vol III: Ebenhaeser Scheme**
18	P WMA 09/E10/00/0417/9	Soil Survey
19		Financial Viability of Irrigation Farming Sub-Report
20	P WMA 09/E10/00/0417/11	Agricultural Production and Farm Development
21		Right Bank Canal Cost Analysis Sub-Report
22		Socio-Economic Impact Analysis Sub-Report
23	P WMA 09/E10/00/0417/12	Socio-Economic Impact Analysis
24	P WMA 09/E10/00/0417/14	Record of Implementation Decisions Report
25	P WMA 09/E10/00/0417/1	Main Report
26	P WMA 09/E10/00/0417/15	Historically Disadvantaged Farmers Report

Concise Description of the Content of Study Reports

Report Index	Report Number	Report Title and Description of Content
1		Inception The report forms part of the contract and stipulates the scope of work for the study, the contract amount and the contract period. It contains a detailed description of tasks and methodology, a study programme, human resource schedule, budget and deliverables. The Capacity Building and Training Plan has been included.
2	P WMA 09/E10/00/0417/2	Capacity Building & Training Year 1 Describes the range of capacity building and training activities planned for the study, and the activities undertaken during the first year of the study, including field-based training, training workshop 1 and mentorship of DWS interns through secondment.
3	P WMA 09/E10/00/0417/3	Capacity Building & Training Year 2 Describes the range of capacity building and training activities planned for the study, and the activities undertaken during the second year of the study, including field-based training, training workshop 2 and mentorship of DWS interns through secondment.
4	P WMA 09/E10/00/0417/4	Water Requirements Assessment Provides an analysis of the existing water use and current water allocations in the study area, and addresses ecological water requirements, water use for irrigated agriculture and projections for future use, current domestic and industrial water use and projections for future use, water use for hydropower and water losses in the water supply system.
5	P WMA 09/E10/00/0417/5	Distribution of Additional Available Water Confirms the volume of additional water available for development, after water has been reserved for the current water uses, as well as making recommendations on how the additional yield should be distributed among water use sectors and water users.
6		Existing Infrastructure and Current Agricultural Development Sub-Report Provides an overview of the extent and general condition of the current bulk water storage and conveyance infrastructure. This report also provides an overview of the locality and extent of the existing agricultural areas determined by reviewing Geographic Information System (GIS) data obtained from various sources.
7	P WMA 09/E10/00/0417/6	Existing Conveyance Infrastructure and Irrigated Land An update of the Sub-Report, providing a refinement of the current agricultural water requirements following evaluation of the current crop types, an assessment of the desirability of diverting releases for downstream irrigators via the Clanwilliam Canal and Jan Dissels River, to meet the summer ecological flows in the lower Jan Dissels River, and presents an Implementation Action Plan with costs.

Report Index	Report Number	Report Title and Description of Content
8		Suitable Agricultural Areas and Land Ownership Sub-Report Description of the collection of information and the preparation undertaken for the analysis of options, which includes a summary of existing irrigated areas and water use, cadastral information, land ownership, environmental sensitivity, soils suitability, water quality considerations and constraints, and the initiation of the process to identify additional areas suitable for irrigation.
9		Evaluation of Development Options Sub-Report Describes the salient features, costs and impacts of identified potential irrigation development options for new irrigation development in the lower Olifants River. This provides the background and an introduction to the discussions at the Options Screening Workshop held in December 2018.
10	P WMA 09/E10/00/0417/10	Suitable Areas for Agricultural Development Describes the supporting information, process followed and the salient features, costs and impacts of identified potential irrigation development options for new irrigation development in the lower Olifants River. Recommends the preferred options to be evaluated at feasibility level.
11		Right Bank Canal Feasibility Design Sub-Report Describes the Design Criteria Memorandum, based on best practice in engineering and complying with recognised codes and standards. Description of route alignments and salient features of the new Right Bank canal. Feasibility-level design of bulk infrastructure, including evaluation of capacities, hydraulic conditions, canal design, surface flow considerations, canal structures, power supply and access roads. Operational considerations and recommendations.
12		Conceptual Design Sub-Report Describes the scheme layouts at a conceptual level and infrastructure components to be designed, alternatives to consider or sub-options, and affected land and infrastructure, as well as the updated recommended schemes for new irrigation development.
13		Environmental Screening Sub-Report Describes and illustrates the opportunities and constraints, and potential ecological risks/impacts and recommendations for the short-listed bulk infrastructure development options at reconnaissance level. Describes relevant legislation that applies to the proposed irrigation developments.

Report Index	Report Number	Report Title and Description of Content
14		Jan Dissels and Ebenhaeser Schemes Feasibility Design Sub-Report Describes the Design Criteria Memorandum, based on best practice in engineering and complying with recognised codes and standards. Description of route alignments and salient features of the Jan Dissels and Ebenhaeser schemes. Feasibility-level design of bulk infrastructure, including evaluation of capacities, hydraulic conditions, intake structures, balancing dams and reservoirs, rising mains and gravity pipelines and trunk mains where relevant, power supply and access roads. Operational considerations and recommendations.
15	P WMA 09/E10/00/0417/13	Feasibility Design Description of the approach to and design of selected bulk infrastructure at feasibility level, with supporting plans and implementation recommendations.
16	P WMA 09/E10/00/0417/7	Topographical Surveys Describes the contour surveys for the proposed identified bulk infrastructure conveyance routes and development areas, the surveying approach, inputs and accuracy, as well as providing the survey information.
17	P WMA 09/E10/00/0417/8	Geotechnical Investigations Presents the findings of geotechnical investigations of the various identified sites, as well as the approach followed, field investigations and testing, laboratory testing, interpretation of findings and geotechnical recommendations.
18	P WMA 09/E10/00/0417/9	Soil Survey Describes the soil types, soil suitability and amelioration measures of the additional area covering about 10 300 ha of land lying between 60 to 100 m above river level, between the upper inundation of the raised Clanwilliam Dam and Klawer.
19		Financial Viability of Irrigation Farming Sub-Report Describes the findings of an evaluation of the financial viability of pre-identified crop-mixes, within study sub-regions, and advises on the desirability of specific crops to be grown in these sub-regions. It includes an evaluation of the financial viability of existing irrigation farming or expanding irrigation farming, as well as the identification of factors that may be obstructive for new entrants from historically disadvantaged communities.
20	P WMA 09/E10/00/0417/11	Agricultural Production and Farm Development This report will focus on policy, institutional arrangements, available legal and administrative mechanisms as well as the proposed classes of water users and the needs of each. This would include identifying opportunities for emerging farmers, including grant and other types of Government and private support, and a recommendation on the various options and opportunities that exist to ensure that land reform and water allocation reform will take place through the project implementation.

Report Index	Report Number	Report Title and Description of Content
21		Right Bank Canal Cost Analysis Sub-Report Provides an economic modelling approach to quantify the risk of the failure of the existing main canal and the determination of the economic viability of the construction of the new right bank canal to reduce the risk of water supply failure.
22		Socio-Economic Impact Analysis Sub-Report Describes the socio-economic impact analysis undertaken for the implementation of the new irrigation development schemes, for both the construction and operational phases. This includes a description of the social and economic contributions, the return on capital investment, as well as the findings of a fiscal impact analysis.
23	P WMA 09/E10/00/0417/12	Socio-Economic Impact Analysis Synthesis of agricultural economic and socio-economic analyses undertaken, providing an integrated description of agricultural production and farm development and socio-economic impact analysis, as well as the analysis of the right bank canal costs and benefits.
24	P WMA 09/E10/00/0417/14	Record of Implementation Decisions Describes the scope of the project, the specific configuration of the schemes to be implemented, the required implementation timelines, required institutional arrangements and the required environmental and other approval requirements and mitigation measures, to ensure that the project is ready for implementation.
25	P WMA 09/E10/00/0417/1	Main Report Provides a synthesis of approaches, results and findings from the supporting study tasks and interpretation thereof, culminating in the study recommendations. Provides information in support of the project funding motivation to be provided to National Treasury.
26	P WMA 09/E10/00/0417/15	Historically Disadvantaged Farmers Report Describes the activities undertaken by an independent consultant to evaluate existing HDI Farmers policies and legislative context, identify, map and analyse prospective HDI farmers and potential land for new irrigation, as well as propose a mechanism for the identification and screening of HDI farmers.

Executive Summary

Introduction

The geotechnical investigations have been conducted with the objective of providing recommendations on the bulk conveyance infrastructure options (new developments / upgrading / rehabilitation) required for the equitable distribution of the existing and additional water from the raised Clanwilliam Dam, as part of the *Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam.*

This report presents the findings of the geotechnical investigation for the **Ebenhaeser Scheme** (Volume III), with Jan Dissels and the Right Bank Canal schemes presented in separate reports, i.e. Volume I and Volume II, respectively.

Scheme description

The Ebenhaeser Scheme will comprise the following elements:

- Retshof Diversion pipeline (Rising Main 1), from the right bank canal of the Olifants River to the left bank canal;
- A new syphon crossing the Olifants River;
- Road crossing at R363;
- Rising Main 2 pipeline (RM2), Vredendal Diversion;
- A 29 000 m3 (28 ML) balancing dam;
- A 2 160 m long Rising Main 3 pipeline between the dam and the reservoir;
- A 10 450 m3 (10.45 ML) concrete reservoir; and
- A 17 300 m long gravity main pipeline.

Regional geology

According to the 1:250 000 scale geological map 3118 Calvinia (Council for Geoscience, 2001), the site is underlain by aeolian sands, and in turn underlain by calcareous soils and graphitic and sericitic schist, phyllite, greywacke, quartzite, impure dolomite, limestone and marble of the Aties Formation, Gariep Supergroup.

Site investigation

A field site visit was conducted by the Aurecon / Zutari design teams on 16th and 17th March 2020 where elements of the various schemes were visited including the Ebenhaeser Scheme. Representatives of the geotechnical team accompanied the two design teams for this visit.

The fieldwork was subsequently conducted between 23rd and 29th July 2020 for the Ebenhaeser Scheme after the approval of the Conceptual Design Sub-report, which recommended viable schemes. The geotechnical investigations included the following elements:

- Test pitting.
- Field testing including Dynamic Cone Penetration (DCP) testing.
- Laboratory testing.
- Interpretation, analysis and reporting.

The findings of the abovementioned fieldwork were presented in the Ebenhaeser Geotechnical Report, Rev01, submitted to DWS in November 2020.

As stated, in places investigation by means of test pits could not be achieved due to the high river levels and the unstable ground, particularly at the Olifants River crossing. Additional investigation was subsequently conducted in January and February 2021. These additional investigations comprised the following;

- geophysical surveys and,
- rotary core borehole (including Standard Penetration testing) .

The findings of these additional investigations have been included in this revised report “Ebenhaeser Geotechnical Report, Rev02”.

Investigation findings

The general geological profile across the scheme’s corridor largely comprises very loose to medium dense, red and orange brown aeolian sand underlain by pedogenic materials (i.e. very dense ferruginised and calcretised sand and hardpan calcrete), terrace gravels and schist bedrock.

The scheme is located outside known areas of natural seismic activity and outside regions of mining-induced seismic activity. As such the site is in a non-seismic activity zone, which means no specific seismic design requirements other than normal structural design requirements are required.

Groundwater seepage was only encountered along the Retshof Diversion. However, the possibility of intersecting seepage elsewhere cannot be completely ruled out, as the presence of ferruginised soils may suggest the occurrence of fluctuating water levels and calcrete indicates a likelihood of the presence of a shallow water table or lateral seepage of groundwater.

The suite of laboratory tests conducted to test the dispersivity of the soils indicates that the materials encountered on site are non-dispersive to highly dispersive. It should be noted that there are some apparent contradictions in the determined dispersivity of soils as per different laboratory test. The chemical tests also indicate a similar contradiction.

The soils along the corridor are generally non-corrosive to extremely corrosive. This indicates that special considerations need to be taken for steel and concrete, particularly for the concrete reservoir, inlet and outlet structure for the balancing dam, and along the pipelines, e.g. in the case of fittings. The HDPE pipe proposed for the scheme is generally not prone to corrosion. Some contradictions between the pH and conductivity results were observed. These are due presence of soluble salts in the soil.

Recommendations

It is understood that the pipelines (i.e. **Rising Mains 1, 2, 3 and the gravity pipeline**) are to be buried. The aeolian sands, pedogenic materials and terrace gravels along the route are suitable as backfill materials with the alluvium encountered along Rising Main 1 being unsuitable.

The foundation depth for the **Balancing Dam** will vary as per refusal in the test pits. This is important in order to achieve maximum stability and impermeability of the founding materials. This indicates that the balancing dam will largely be founded on dense to very dense, calcretised and ferruginised sand with occasional hardpan calcrete.

The **concrete Reservoir** should be founded on the very dense, calcretised and ferruginised sand (hardpan calcrete) to allow for adequate bearing capacity. The ground conditions at the reservoir can be subdivided into shallow hardpan on the western side and deeper pedogenic material on the eastern and southern sides. This is likely to require a cut of 2.5 m or deeper to found on the hardpan. Alternatively, compacted backfill below the structure could be considered on the eastern and southern sides of the reservoir.

Test pit sidewalls largely collapsed in the very loose to medium dense aeolian sands during the field investigations. The stability of excavations during construction may be compromised and shoring and/or battering of excavations will be required. Assessment would be required for deeper excavations left open for longer periods. This should be conducted by a suitably qualified and experienced geotechnical practitioner.

Soft excavations in terms of SANS 1200D are to be expected in aeolian sand, alluvium and terrace gravels. *Hard excavations*, as per SANS 1200D, are encountered in hardpan calcrete and schist bedrock.

At the time of compiling the geotechnical report the invert level for the pipelines had not been finalized by the design team hence comparison between the invert level and refusal has not been included.

It is recommended that foundation excavations at the Balancing Dam and the concrete Reservoir be inspected by an experienced geotechnical engineer or engineering geologist prior to placement of materials to ensure that the desired founding materials / horizons have been attained.

It is recommended that additional chemical testing be conducted to investigate the corrosiveness of the soils along the pipeline routes.

The Olifants river crossing is expected to comprise a syphon, not more than 8m deep. Based on borehole data from the additional investigation, deep alluvial soils extending to at least 8m below NGL are expected, coupled with high water levels. The base of the alluvial deposits was not intersected, and neither the depth of the underlying bedrock nor the bedrock condition is confirmed. The alluvial deposits comprise fine-grained sediments and might be considered relatively uniform. This relatively uniform profile within the upper 8m implies that differential settlement is not anticipated.

Unsupported excavations within the river section, within these saturated alluvial sands, will be prone to collapse. All excavations will therefore either require battering or support, such as shoring, or combinations thereof. It is doubtful whether battering slopes to safe angles will be practical, as these slopes would of necessity be very flat, and would be subject to continual collapse.

The alluvial sands to a depth of at least 8 m below NGL will classify as ‘soft excavations’ in accordance with SANS 1200 D. The profile might include occasional cobbles / boulders, even though the two boreholes did not intersect such materials and the selected excavation methods must be able to deal with a coarser fraction.

List of abbreviations

AASHTO = American Association of State and Highway Transport Officials

BH = borehole

CBR = California Bearing Ratio

CH = Chainage

COLTO = Committee of Land Transport Officials

DCP = Dynamic Cone Penetrometer

DWS = Department of Water & Sanitation

ESP = Extractable Sodium Percentage

FI = Foundation Indicator

g = acceleration due to gravity (9.8 m.s^{-2})

GM = Grading modulus

LL = Liquid Limit

LS = Linear Shrinkage

MDD = Maximum Dry Density

OMC = Optimum Moisture Content

PGA = Peak Ground Acceleration

PHSA = Probabilistic Seismic Hazard Analysis

PI = Plasticity Index

PL = Plastic Limit

PR + Penetration rate

SAICE = South African Institution of Civil Engineering

SAR = Sodium Adsorption Ratio

TLB = Tractor-loader backhoe (light)

TP = Test pit, or trial pit

USCS = Unified Soil Classification System

WPI = Weighted Plasticity Index

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Appendix I

Probabilistic Seismic Hazard Analysis for the Clanwilliam Dam (excerpt from Aurecon Report 106310-G5-01 Clanwilliam Dam: Second Engineering Geological Report for Design of Dam Raising)

1 Introduction

The objective of the *Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam* is to provide recommendations on the bulk conveyance infrastructure options (new developments / upgrading / rehabilitation) required for the equitable distribution of the existing and additional water from the raised Clanwilliam Dam, after investigation of:

- The existing water allocation and projections for the supply area;
- New areas for agricultural development;
- Options for the required conveyance infrastructure; and
- Appropriate farming models and cost of irrigation water.

The study has recommended that the feasibility designs of the following three schemes be prepared;

- Jan Dissels;
- Right Bank Canal; and
- Ebenhaeser.

To support the respective feasibility designs for these schemes, geotechnical investigations were initiated at a stage when respective scheme layouts were close to being finalised. In this way, geotechnical inputs were able to serve as input considerations prior to finalisation of layouts, although the primary aim of the geotechnical investigations was to support the respective feasibility designs.

The findings of the geotechnical investigations are presented separately for each of the respective schemes, as shown below (this report is shown in **bold**);

- Geotechnical Investigations Report. Volume I. Jan Dissels Scheme.
- Geotechnical Investigations Report. Volume II. Right Bank Canal Scheme.
- **Geotechnical Investigations Report. Volume III. Ebenhaeser Scheme.**

2 Scheme description

The Ebenhaeser Scheme starts at the existing canal on the right flank of the Olifants River. This portion of the scheme is termed the Retshof Diversion. Rising Main 1 traverses through the Olifants River and includes a new syphon for the river crossing.

Water will also be diverted from the existing left flank canal via Rising Main 2 (Vredendal Diversion) combined with RM1 and pumped into a balancing dam. The balancing dam is understood to be a lined earth fill dam located close to the Vredendal left bank canal diversion point. Water will be pumped via the Rising Main 2 pipeline into the dam and pumped from there to the concrete reservoir via the Rising Main 3 pipeline. Water will then be gravitated for about 17 km via the gravity pipeline to the Ebenhaeser community.

Details of the scheme are to be found in the Conceptual Design Report and are not described in this report in any detail.

The Ebenhaeser Scheme will comprise the following elements (**Figure 1**);

- The Retshof Diversion pipeline (Rising Main 1), from the right bank canal (of the Olifants River) to the left bank canal;
- A new syphon crossing the Olifants River;
- Road crossing of R363;
- Rising Main 2 pipeline (RM2), Vredendal Diversion;
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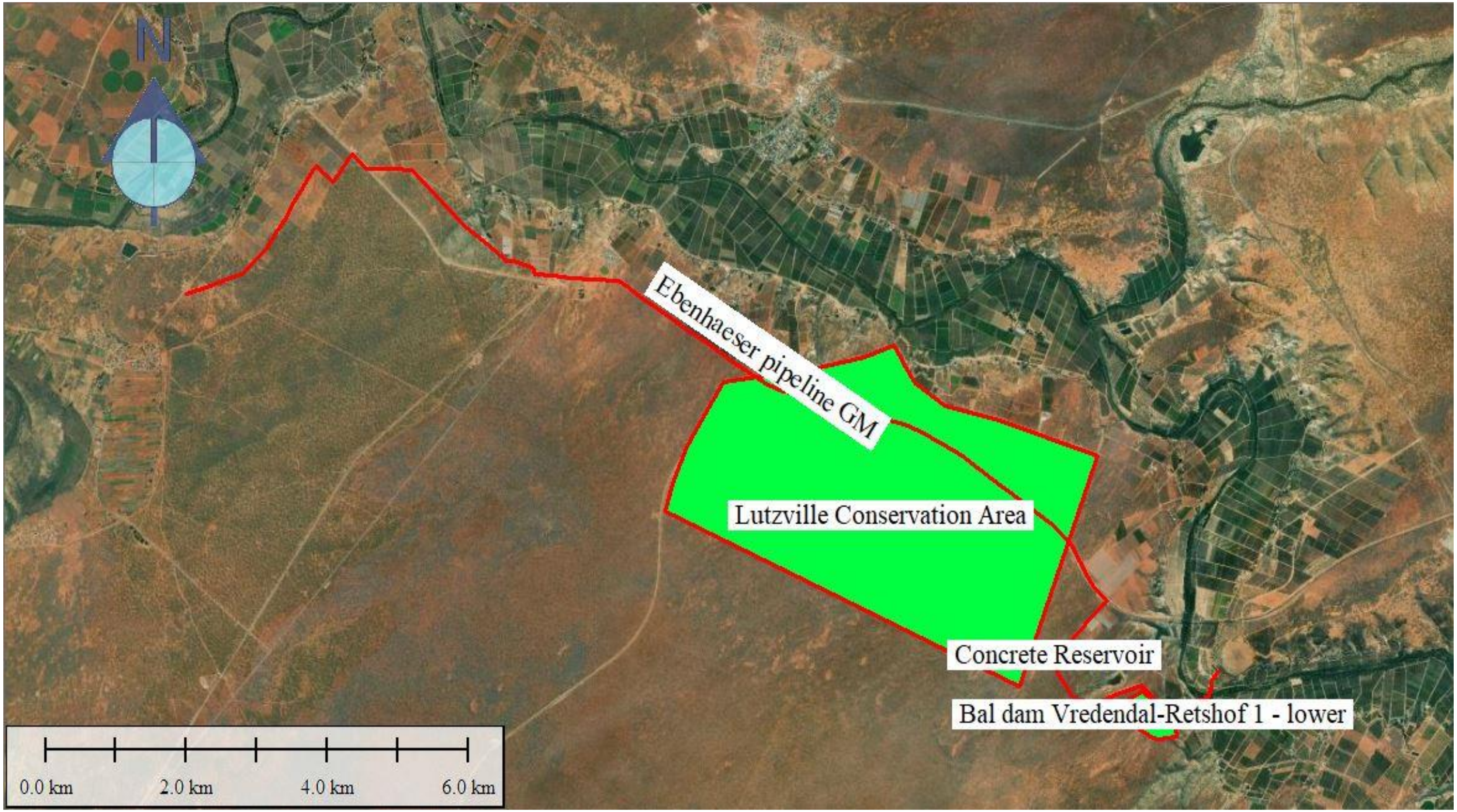


Figure 1: Layout of the Ebenhaeser Scheme

3 Investigation methodology

The investigation commenced with a desk study and site reconnaissance visit conducted by the Aurecon / Zutari design and geotechnical teams. Subsequently, test pitting, Dynamic Cone Penetration testing, soil profiling as well as selection of representative samples for laboratory testing was conducted by the geotechnical team. The findings of the abovementioned fieldwork were presented in the Ebenhaeser Geotechnical Report, Rev01, submitted to DWS in November 2020.

As stated, in places investigation by means of test pits could not be achieved due to the high river levels and the unstable ground, particularly at the Olifants River crossing. Additional investigation was subsequently conducted in January and February 2021. These additional investigations comprised the following;

- geophysical surveys and,
- rotary core borehole (including Standard Penetration testing).

The findings of these additional investigations have been included in this revised report “Ebenhaeser Geotechnical Report, Rev02”.

3.1 Desk study and reconnaissance visit

A field reconnaissance visit was conducted by the Aurecon / Zutari design teams on 16th and 17th March 2020 where elements of the various schemes were visited. Representatives of the geotechnical team accompanied the two design teams for this visit. No intrusive geotechnical investigations were carried out during this visit which was confined to walk-over surveys and general observations.

Prior to the visit, as well as post-visit, a desk study was carried out of available data and other relevant information. Available information that was consulted is listed below:

- Geological Maps, 1:250 000 Geological Map (Sheet 3118 Calvinia) Council for Geoscience, 2001.
- Satellite imagery (Google Earth).

- Survey data.

Other relevant publications are cross-referenced in the text and listed in Section 8.

3.2 Fieldwork

Fieldwork scoping could only commence when there was reasonable certainty regarding the layout of the three schemes. Certain elements could only be finalised after the reconnaissance field visit in March 2020, which allowed detailed scoping of the required fieldwork. The geotechnical investigation at the Ebenhaeser Scheme included all sub-options as outlined in Section 2.

A major complication with the execution of the fieldwork was experienced due to the national COVID-19 lockdown. This lockdown did not allow fieldwork, and only after Level 3 was announced, was it possible to commence with fieldwork when the necessary permits were in place.

Fieldwork primarily comprised a test pitting programme, complimented by a laboratory testing programme. Further details are elaborated below.

3.2.1 Overall Health and Safety

The field teams were fully compliant with Occupational Health and Safety legislation. A detailed safety file was prepared prior to commencing with fieldwork, complete with risk assessments, and formalised Section 8 (2) i appointments.

Additional measures were also instituted in recognition of COVID regulations. These included logging daily temperature measurements, wearing of face masks, maintaining social distancing, etc.

With the fieldwork essentially comprising test pitting, there was a big focus on test pit safety. This included the following:

- Field teams comprising two persons, as per the SAICE Geotechnical Division guidelines (SAICE, 2007). Each team was under the leadership of an experienced, professionally registered individual.
- Carrying out a risk assessment for each test pit prior to entering. These risk assessments were conducted by the appointed Competent Person.
- Fully briefing the TLB operators regarding safe practices and expectations in this regard.
- Ensuring the spoil heap was not located on the edge of the test pit, to avoid unnecessary surcharge on the sidewalls.

- Where test pits were deemed safe to enter, a ramp was excavated at the one end to facilitate easy entrance / exit.
- Where there were concerns regarding the sidewall stability, the test pits were deemed unsafe for entry, and the profiling and sampling were done from surface.
- All test pits were closed immediately after profiling and sampling had been completed. No test pits were left open overnight.

3.2.2 Test pitting

Test pits were excavated from the Retshof diversion towards the balancing dam and concrete reservoir sites, and along the gravity pipeline route, all the way to Ebenhaeser. A total of eighty-three (83 No) test pits were profiled for the scheme. A test pit summary is presented below in **Table 1**, indicating the positions, maximum attained depths of the test pits, as well as conditions encountered at the termination depth.

Test pit positions are indicated on the site layout plans in **Appendix A** (Dwg 113834-0001-DRG-GG-0001-A to 113834-0001-DRG-GG-0004-A). Access difficulties and proximity to the Olifants River at the river crossing location meant test pits could not be excavated. Cut faces and rock outcrops were assessed and profiled where possible.

The test pits were excavated using two Bell 315SK light tractor-loader backhoes (TLB’s), supplied to the geotechnical team by the Construction South team of the Department of Water and Sanitation (DWS). The investigations were conducted between 23 and 29 July 2020.

Test pits were excavated to 3 m depth, unless refusal was encountered at shallower depth, or the conditions were deemed unsafe. An average test pit spacing of 300 m was targeted. In places, a closer spacing was utilised, for example at the concrete reservoir and the balancing dam. The test pits were profiled by registered engineering geologists in accordance with accepted Southern African standards (as per Jennings, Brink, and Williams, 1973). A summary of soil and rock profile description terminology is provided in **Appendix B.**

Test pit positions were recorded with a Garmin hand-held GPS and are presented in a South African grid format, WGS84 datum. The test pit profiles with accompanying photographs are presented in **Appendix C.**

Table 1: Test pit summary

Test pit no	Proposed structure	Coordinates (SA Lo 19 WGS 84)		Termination depth	Remarks
		X	Y		
E-TP 01	Rising Main 1 pipeline (RM1) Retshof Diversion	- 56066	- 3500000	3.0	No refusal, profiled exposed cut face
E-TP 02		- 56169	- 3500132	1.5	No refusal, profiled exposed cut face
E-TP 03		- 56216	- 3500301	-	Not excavated, due to proximity to the river. Profile expected to be similar to E-TP07
E-TP 04		- 56193	- 3500305	-	
E-TP 05		- 56197	- 3500340	-	
E-TP 06		- 56220	- 3500336	-	
E-TP 07		- 56404	- 3500747	3.0	No refusal, terminated in alluvium material
E-TP 08	Rising Main 2 pipeline (RM2) Vredendal Diversion	- 56562	- 3500514	1.5	Not excavated, profiled schist outcrop on slope along the existing canal.
E-TP 09		- 56719	- 3500508	3.0	No refusal, terminated on loose to medium dense aeolian sand.
E-TP 10	Balancing Dam	- 56714	- 3501122	2.3	Difficult excavation, dense ferruginised and calcretised sand. Pedogenic
E-TP 11		- 56955	- 3500895	1.4	Refusal, very dense ferruginised and calcretised sand. Pedogenic
E-TP 12		- 57186	- 3501076	1.5	Refusal on hard rock schist
E-TP 13		- 57350	- 3500533	2.0	Refusal, very dense ferruginised and calcretised sand. Pedogenic
E-TP 14		- 57180	- 3500676	2.6	Refusal, very dense ferruginised and calcretised sand. Pedogenic
E-TP 15		- 56984	- 3500417	1.4	Refusal, very dense ferruginised and calcretised sand. Pedogenic
E-TP 16		- 56800	- 3500612	1.1	Refusal, very dense terrace gravels

Test pit no	Proposed structure	Coordinates (SA Lo 19 WGS 84)		Termination depth	Remarks
		X	Y		
E-TP 17		- 56939	- 3500687	1.7	Refusal, very dense ferruginised and calcretised sand. Pedogenic
E-TP 18		- 57137	- 3500819	2.0	No refusal, terminated on loose to medium dense aeolian sand
E-TP 19	Rising Main 3 pipeline (RM3) from balancing dam to concrete reservoir	- 57508	- 3500316	-	Not excavated due to no site access
E-TP 20		- 57791	- 3500420	-	Not excavated due to no site access
E-TP 21		- 58165	- 3500626	0.7	Refusal on soft to medium hard schist.
E-TP 22		- 58266	- 3500145	2.0	Refusal on assumed hardpan calcrete, but hole collapsed.
E-TP 23		- 58440	- 3499887	2.5	No refusal, terminated on loose to medium dense aeolian sand
E-TP 24	Concrete reservoir	- 58511	- 3499819	0.8	Refusal, very dense ferruginised and calcretised sand. Pedogenic
E-TP 24 ADD		- 58522	- 3500123	2.2	No refusal, terminated on loose to medium dense aeolian sand
E-TP 25		- 58465	- 3499783	2.4	Refusal on hardpan calcrete
E-TP 26	Gravity main pipeline	- 58215	- 3499636	1.8	Refusal, very dense ferruginised and calcretised sand. Pedogenic
E-TP 27		- 58004	- 3499417	0.5	Refusal on medium hard rock schist
E-TP 28		- 57775	- 3499208	2.5	Refusal on hardpan calcretised and ferruginised sand.
E-TP 29		- 57753	- 3499278	2.3	No refusal, terminated on loose to medium

Test pit no	Proposed structure	Coordinates (SA Lo 19 WGS 84)		Termination depth	Remarks
		X	Y		
					dense aeolian sand
E-TP 30		- 57951	- 3499043	1.3	Refusal on hardpan calcrete
E-TP 31		- 58096	- 3498788	0.65	Refusal on hardpan calcrete
E-TP 32		- 58224	- 3498240	1.8	Refusal on hardpan calcrete
E-TP 33		- 58436	- 3498034	1.6	Refusal, very dense ferruginised and calcretised sand. Pedogenic
E-TP 34		- 58696	- 3497847	2.5	No refusal, terminated on loose to medium dense aeolian sand
E-TP 35		- 58954	- 3497674	1.5	Refusal, very dense ferruginised and calcretised sand. Pedogenic
E-TP 36		- 59196	- 3497506	1.0	Refusal on hardpan calcrete
E-TP 37		- 59449	- 3497337	1.2	Refusal on hardpan calcrete
E-TP 38		- 59694	- 3497163	1.1	Refusal on hardpan calcrete
E-TP 39		- 59948	- 3497015	0.5	Refusal on hardpan calcrete
E-TP 40		- 60210	- 3496865	2.0	Refusal on hardpan calcrete
E-TP 41		- 60485	- 3496754	0.9	Refusal on hardpan calcrete
E-TP 42		- 60769	- 3496672	0.6	Refusal on hardpan calcrete
E-TP 43		- 61120	- 3496872	1.3	Refusal on hardpan calcrete
E-TP 44		- 61401	- 3496753	1.1	Refusal on hardpan calcrete
E-TP 45		- 61723	- 3496692	1.1	Refusal on hardpan calcrete
E-TP 46		- 61988	- 3496622	0.9	Refusal on very soft rock schist.
E-TP 47		- 62302	- 3496593	0.5	Logged cut face, schist outcrop in the area.
E-TP 48		- 62588	- 3496479	2.4	No refusal, terminated on loose aeolian sand

Test pit no	Proposed structure	Coordinates (SA Lo 19 WGS 84)		Termination depth	Remarks
		X	Y		
E-TP 49		- 62850	- 3496314	2.5	No refusal, terminated on medium dense aeolian sand
E-TP 50		- 63109	- 3496151	1.4	Refusal on hardpan calcrete
E-TP 51		- 63372	- 3495982	1.0	Refusal on hardpan calcrete
E-TP 52		- 63624	- 3495823	0.7	Refusal on hardpan calcrete
E-TP 53		- 63874	- 3495654	1.5	Refusal on hardpan calcrete
E-TP 54		- 64133	- 3495478	0.9	Refusal on hardpan calcrete
E-TP 55		- 64382	- 3495314	0.7	Refusal on hardpan calcrete
E-TP 56		- 64632	- 3495151	1.1	Refusal on hardpan calcrete
E-TP 57		- 64919	- 3495108	1.9	Refusal on hardpan calcrete
E-TP 58		- 65229	- 3495089	0.2	Refusal on hardpan calcrete
E-TP 59		- 65690	- 3495115	1.5	Refusal on hardpan calcrete
E-TP 60		- 65836	- 3495035	0.4	Refusal on hardpan calcrete
E-TP 61		- 66076	- 3494899	2.1	Refusal on hardpan calcrete
E-TP 62		- 66350	- 3494809	-	Not excavated, schist outcrop in the area,
E-TP 63		- 66601	- 3494618	0.75	Refusal on very soft rock schist
E-TP 64		- 66837	- 3494371	4.0	Logged a cut face of redundant road
E-TP 65		- 67046	- 3494221	0.4	Refusal on hardpan calcrete
E-TP 66		- 67272	- 3494001	1.3	Refusal on hardpan calcrete
E-TP 67		- 67483	- 3493799	1.4	Refusal on hardpan calcrete
E-TP 68		- 67733	- 3493672	0.3	Refusal on hardpan calcrete
E-TP 69		- 68045	- 3493652	2.5	Refusal on hardpan calcrete, logged a cut face of a borrow pit.
E-TP 70		- 68344	- 3493589	0.4	Refusal on hardpan calcrete

Test pit no	Proposed structure	Coordinates (SA Lo 19 WGS 84)		Termination depth	Remarks
		X	Y		
E-TP 71		- 68543	- 3493553	0.5	Refusal on hardpan calcrete
E-TP 72		- 68701	- 3493776	1.3	Refusal on hardpan calcrete
ETP 73		- 68925	- 3493651	0.6	Refusal on hardpan calcrete
E-TP 74		- 69167	- 3493862	1.2	Logged open pit, terminated on hardpan calcrete
E-TP 75		- 69307	- 3494029	2.1	Logged open pit, terminated on hardpan calcrete
E-TP 76		- 69411	- 3494269	1.2	Logged open pit, terminated on hardpan calcrete
E-TP 77		- 69585	- 3494570	0.15	Refusal on hardpan calcrete
E-TP 78		- 69792	- 3494858	0.6	Refusal on hardpan calcrete
E-TP 79		- 69985	- 3495017	0.4	Refusal on hardpan calcrete
E-TP 80		- 70244	- 3495135	0.4	Refusal on hardpan calcrete
E-TP 81		- 70526	- 3495248	-	Refusal on hardpan calcrete on surface
E-TP 82		- 70817	- 3495341	0.4	Refusal on calcretised schist, immediate surroundings on calcretised schist

3.2.3 Dynamic Cone Penetration testing

The dynamic cone penetration (DCP) test is conducted by driving a 20 mm diameter, 60° cone into the ground by an 8-kg hammer. The hammer is lifted by hand and dropped 575 mm and the results are expressed as the penetration rate (PR) in mm per blow. Four 1.0 m DCP tests were conducted adjacent to the test pit positions along the gravity pipeline to evaluate and correlate the stiffness of the soil profile. Where shallow refusal was encountered at the test pits no DCP tests were conducted.

Results obtained from the dynamic cone penetrometer give a rough indication of the consistency of the soil. The relationship between the penetration rates and material description, as shown in **Table 2**, is regarded as a guideline for *non-cohesive soils*.

Detailed results are included in **Appendix D.**

Table 2: Correlation of soil consistency to the penetration rate

Penetration rate (mm / blow)	Material description
> 75	Very loose
40 - 75	Loose
15 - 30	Medium dense
5 – 15	Dense
< 5	Very dense

3.2.4 Laboratory testing

The majority of laboratory tests have been carried by Steyn Wilson Laboratories (Pty) Ltd., who were appointed by means of a competitive bidding process. Duplicate samples, approximately 10%, were submitted to another independent laboratory, Labco South Africa (Pty) Ltd., essentially for quality control purposes.

The tests conducted and respective quantities are summarised in **Table 3** and **Table 4** for the bulk and duplicate samples respectively. Detailed laboratory test results are included in **Appendix** E and are summarised within the text.

Table 3: Bulk sample quantities for laboratory testing by Steyn Wilson Laboratories

Test	Quantity
Foundation Indicators, comprising grading analyses (both sieve as well as hydrometer) as well as Atterberg limits and Linear Shrinkage	35
Mod AASHTO Compaction and CBR	15
Chemical tests, including pH and conductivity	20
Quick Direct Shear (at 98% Compaction) (Shear box)	13
Dispersiveness suite (pinhole, crumb, double hydrometer and chemical test (SAR and ESP))	15
Collapse potential	3
Falling head permeability test	8

Table 4: Duplicate sample quantities submitted for testing at Labco

Test	Quantity
Foundation Indicators, comprising grading analyses (both sieve as well as hydrometer) as well as Atterberg limits and Linear Shrinkage	7
Mod AASHTO Compaction and CBR	3
Dispersiveness suite (pinhole, crumb, double hydrometer and chemical test (SAR and ESP))	3
Chemical tests, including pH and conductivity	7

3.2.5 Geophysical surveys

Cape Geophysics was appointed to carry out an electrical resistivity survey, specifically Electrical Resistivity Tomography (ERT), to inform on the subsurface geological structure and specifically resistivity anomalies, as a precursor to confirming borehole positions.

Two traverses were carried out at the river crossing at the Ebenhaeser Scheme, both parallel to the river, on the respective left and right river banks. Traverses are listed below (**Table 5**) and the test locations are shown in **Figure 2**.

Table 5: Geophysical survey coordinates

Location	Coordinates (SA Lo 19 WGS 84)	
	X	Y
Traverse 7, right bank		
Downstream end	-56262.81	-3500288.63
Upstream end	-56144.45	-3500297.87
Traverse 8, left bank		
Downstream end	-56264.75	-3500334.01
Upstream end	-56147.02	-3500348.89

Figure 2: Location of field resistivity tests.

Detailed description of the methodologies, the equipment used, as well as the results, are presented in **Appendix F**. The findings are incorporated into the discussion on the geological profiles encountered.

3.2.6 Rotary core drilling

Two (2 No.) rotary core boreholes (BH E01 and BH E02) were drilled at selected positions on the respective river banks to investigate the deeper profile at the proposed river crossing. The aim of this drilling was to extend the information to depths not previously able to be investigated by means of test pits alone.

Specialist geotechnical drilling contractor BS Moloi Drilling were appointed via a competitive bidding process to carry out the drilling. Boreholes were drilled in accordance with accepted South African standards (COTO, 2010). Standard Penetration Tests (SPT's) were conducted at 1.5 m depth intervals until refusal in the boreholes.

The detailed borehole profile descriptions and core photographs are included in **Appendix G**. A summary of the borehole information is shown in **Table 6** below:

Table 6: Borehole summary

Hole number	Coordinates (Lo 19 WGS 84)		Borehole collar Elevation** (masl)	Depth to bedrock (m)	Total depth (m)	Orientation and Comments
	X	Y				
BH E01	-56200.94	-3500304.49	10	-	7.75	Vertical; SPT's
BH E02	-56205.82	-3500340.06	9	-	7.95	Vertical: SPT's

***** NOTE: Collar elevations provided in Table 6 was not derived from surveys. These are estimated values and should therefore be considered as approximate.***

3.2.7 Standard Penetration Testing

Standard Penetration Tests (SPT) were conducted in the boreholes to confirm the consistency of the material on site.

The SPT is conducted by driving a split spoon sampler into the ground using a 63,5 kg hammer. The hammer is mechanically lifted and dropped a vertical distance of 762 mm. The SPT spoon is driven 450 mm into the ground and the number of blows required for the final 300 mm of penetration (referred to as the N-value) is recorded on the borehole profile descriptions. A guideline for the relationship between the SPT N-values and consistency of cohesive and non-cohesive soil are given in **Table 7**.

Table 7: Correlation of SPT N-values with soil consistency for non-cohesive soils (Franki, 2008)

Cohesive soils		Non-Cohesive soils	
N-Value	Material Consistency	N-Value	Material Consistency
1 – 2	Very soft	< 4	Very loose
2 – 4	Soft	4 – 10	Loose
4 – 8	Firm	10 – 30	Medium dense
8 – 15	Stiff	30 – 50	Dense
15 – 30	Very stiff	> 50	Very dense

SPT results are embedded into the borehole profile descriptions included in **Appendix G**.

4 General geology

4.1 Stratigraphy and lithologies

According to the 1:250 000 scale geological map 3118 Calvinia (Council for Geoscience, 2001), the Ebenhaeser scheme is located in an area underlain by graphitic and sericitic schist, phyllite, greywacke, quartzite, impure dolomite, limestone and marble from the Aties Formation (Nat), Gariep Supergroup. These lithologies are covered predominantly by Quaternary aged calcareous soil (Q-r$_2$) towards the north-western portion along the gravity pipeline route, and red aeolian sand (Ç-s) towards the centre and south-east (**Figure 3**).

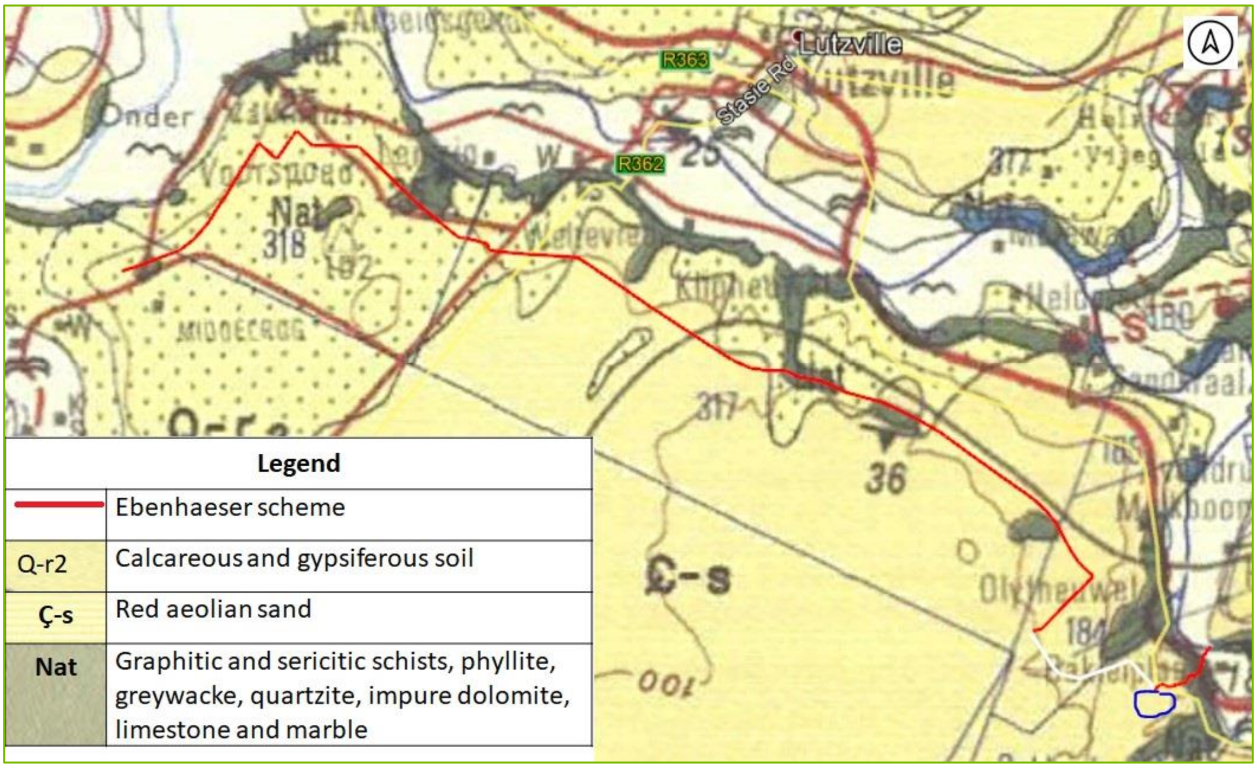


Figure 3: Ebenhaeser Scheme, extract from the 1:250 000 scale geological map 3118 Calvinia (Council for Geoscience, 2001)

4.2 Structural geology

The principal rock types in the vicinity of the Ebenhaeser Scheme are schists and greywackes dipping at 20° to 40° in the southerly and south-westerly directions.

The Cape Fold Belt also affected the sequence of sedimentary rock layers of the Gariep Supergroup through faulting, folding and subsequent weathering. This has produced a rugged mountainous terrain characterised by a sequence of elevated ridges and peaks separated by broad linear valleys. No major faulting or folding was noted in the area, probably due to the fact that most of the scheme area has been covered by the recent sediments. However, the general area was affected by the regional Cape Fold Belt, a fold and thrust belt of late Palaeozoic age.

4.3 Seismicity and seismic hazard

The Peak Ground Acceleration (PGA) associated with the area is roughly 0.05 g, with a 10% probability of being exceeded in a 50-year period (**Figure 4**). According to (SANS 10160-4: 2011), the scheme is located outside natural seismic activity and outside the region of mining-induced seismic activity. It is considered a non-seismic activity zone and as such, no specific seismic design requirements, other than normal structural design requirements, are required.

A Probabilistic Seismic Hazard Analysis (PSHA) was conducted for the raising of the Clanwilliam Dam (Kijko, 2011). The full PSHA report was part of the ‘Second Engineering Geological Report for Design of Dam Raising’, compiled by Zutari (then Aurecon) for DWS (then the Department of Water Affairs), and is included in this report as **Appendix G**.

A brief summary below covers testing procedure, methodology, results and the detailed discussions can be obtained from Section 5: Seismic Hazard Assessment of Aurecon - issued in January 2012.

The PSHA considered all previously recorded earthquakes within a radius of 320 km of the Clanwilliam Dam. Given the existence of four faults in vicinity of the dam site, an investigation of the effect of seismic activity of the faults on the seismic hazard assessment was performed. A key assumption of this PSHA is that the structure is founded on hard rock; considered to be true in the case of this mass concrete dam.

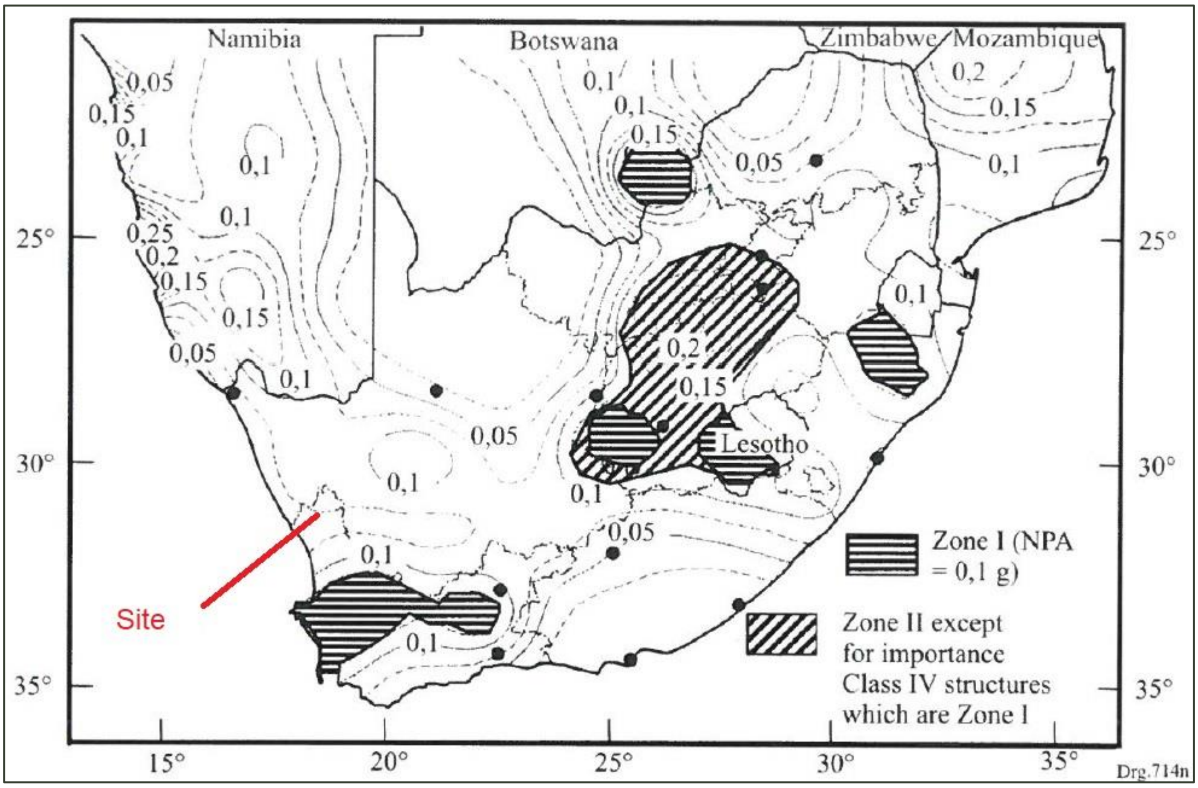


Figure 4: Seismic hazard map showing peak ground acceleration (g) with 10% probability of being exceeded in a 50-year period (SANS 10160-4: 2011)

The results were given in terms of mean return periods and probabilities of being exceeded for specified values of horizontal component of the PGA, with subsequent conversion to yield the vertical component of PGA.

Importantly, the PSHA incorporates a number of uncertainties, the main ones being the lack of a reliable regional ground motion prediction equation and lack of seismic potential of four identified faults in vicinity of the dam. These uncertainties were considered through logic tree formalism that allowed inclusions of alternative scenarios and interpretations that are weighted according to their probability of being correct.

After application of logic tree formalism to the uniform horizontal ground acceleration spectra, the expected values for the horizontal component of the Operating Basis Earthquake (OBE), Maximum Design Earthquake (MDE) and the Maximum Credible Earthquake (MCE) are listed below in **Table 8**.

Table 8: Expected values for OBE, MDE and MCE (after logic tree formalism), after Kijko, 2011

	Return period	PGA (g)
OBE	Return period of 144 years (equivalent to 50% probability in 100 years)	0,078 ± 0,045
MDE	Return period of 475 years (equivalent to 10% probability in 50 years)	0,140 ± 0,090
MCE	Return period of 10 000 years	0,402 ± 0,309

4.4 Weathering and soils

The area can be classified as having an arid to semi-arid climate with relatively low annual rainfall. The climate is characterised by fog and dew falls that supplement the low rainfall, and leads to high humidity and relatively cool night temperatures.

Erosion gullies on the side slopes of the existing canal along the proposed Retshof and Vredendal diversion of the Ebenhaeser Scheme were observed. Recent sediments largely overly the bedrock and are mainly exposed by the Olifants River. These sediments comprise red aeolian sand and calcareous soils of varying thickness.

Mechanical disintegration is the dominant mode of rock weathering in areas of lower rainfall, whereas chemical decomposition dominates in areas of higher rainfall. This is summarised via the widely used Weinert's climatic N-value (Weinert, 1980), where essentially mechanical disintegration occurs with $N > 5$ (more arid) and chemical decomposition where $N < 5$ (more humid). The N-value is calculated from climatic data as follows:

$$N = 12.Ej /Pa$$

where: Ej = evaporation during January

Pa = annual precipitation (adapted from Brink, 1983).

The Cape West Coast lies on the dry side of the country with a Weinert's climatic N value of between 7.5 and 20 (**Figure 5**). In this region of the country, residual soils are generally of limited thickness and disintegration is the dominant form of weathering.

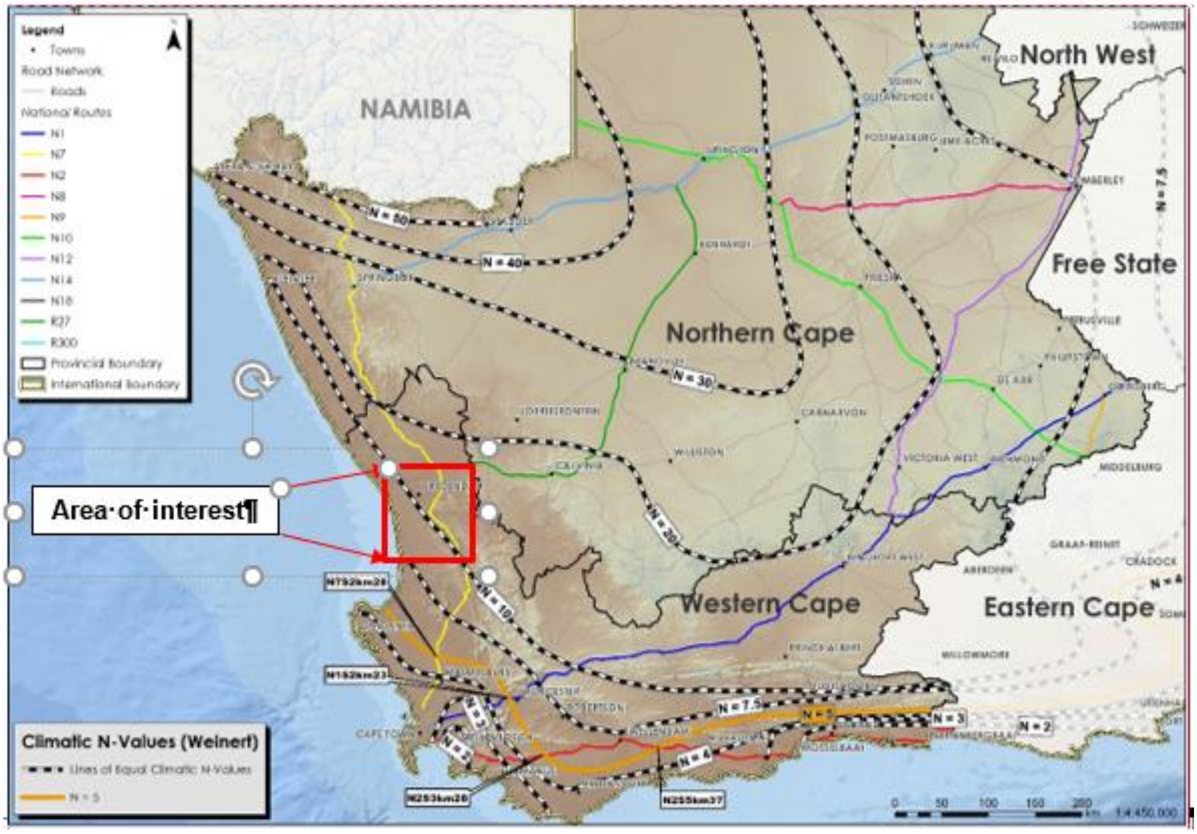


Figure 5: Climatic N-values for the area of interest, after Weinert (1980)

5 Investigation findings

5.1 Site description

The diversions are located on the flanks of the Olifants River (dwg 113834-0001-DRG-GG-0001-A) where the right flank, lower left flank and the river section are largely characterised by aeolian sands and alluvium material. The RM1 route traverses a floodplain and the topography near the river is generally flat.

The upper left flank is characterised by rock outcrop of the highly weathered schist bedrock, which is associated with steep slopes. The topography in this area (i.e. left flank of RM1 and RM2 routes) is generally moderately to gently sloping towards the dam and reservoir.

The remainder of the route is generally flat all the way to Ebenhaeser with a few moderate to steep slopes.

Natural vegetation is mainly shrubs, bushes and grass. Trees were encountered along the Olifants River. The route traverses a few cultivated areas, and sand dunes which are located mainly in the mid-section of the route.

5.2 Geological profile and zonation

Several different geological profiles have been encountered along the scheme. A distinction between the profiles has been made according to the origin of the soils, allowing different geological zones to be defined. Most of the route is covered by aeolian sand or colluvium underlain by pedogenic materials, terrace gravels and schist bedrock.

The geological zones have been classified as Zones 1 to Zone 15 and are summarised in **Table** 9, with each zone described in more detailed below. Test pits E-TP15 and E-TP16 cover both the dam and the Rising Main 3, in particular the vicinity of the inlet / outlet area, and as such they are repeated under both element summaries.

The zonation is based on test pit information and general observations of the site, and variability between test pit positions cannot be excluded. The zonation has been presented in a sequence i.e. from Chainage 00 to Chainage 20 676 along the pipeline route. Refer to the site layout plans (Dwg 113834-0001-DRG-GG-0001-A to 113834-0001-DRG-GG-0004-A) in **Appendix A**.

Table 9: Geological zonation of the Ebenhaeser Scheme

Geological zonation	Applicable test pits	Approximate chainages	Summary of the general geological profile
1	E-TP01, E-TP02 and E-TP07	00 to 300 and 500 to 720	Alluvium underlain by calcretised and ferruginised sand (calcrete)
2	E-TP03 to E-TP06	300 to 500	Olifants River crossing: alluvial materials
3	E-TP08	720 to 1 000	Schist outcrop or shallow bedrock
4	E-TP09	1 000 to 1 120	Aeolian sand
5	E-TP10 to E-TP18	1 197 to 1 200	Balancing dam: aeolian sand underlain by hardpan calcrete, terrace gravels and schist bedrock
6	E-TP15, 16, 19 and E-TP20	1 120 to 2 460	Aeolian sands underlain by calcretised and ferruginised sand (hardpan calcrete)
7	E-TP21	2 460 to 2 800	Colluvium overlying highly to moderately weathered schist
8	E-TP22 to E-TP23	2 800 to 3 300	Aeolian sands underlain by calcretised and ferruginised sand (hardpan calcrete)
9	E-TP24 to E-TP25	3 300 to 3 400	Concrete reservoir: aeolian sand underlain by hardpan calcrete
10	E-TP26 to E-TP44	3 400 to 9 500	Aeolian sands underlain by calcrete
11	E-TP45 to E-TP47	9 500 to 10 100	Schist outcrop or shallow bedrock
12	E-TP48 to E-TP61	10 100 to 14 400	Aeolian sands underlain by calcrete
13	E-TP62 to E-TP64	14 400 to 15 600	Schist outcrop or shallow bedrock
14	E-TP65 to E-TP81	15 600 to 20 500	Aeolian sands underlain by calcrete
15	E-TP82	20 500 to 20 676	Schist outcrop or shallow bedrock

5.2.1 Zone 1: Aeolian sand underlain by calcretised and ferruginised sand (calcrete)

This zone, which forms part of the Retshof Diversion Rising Main 1 pipeline route, is characterised by brown, loose to medium dense, pinholed, silty sands of aeolian origin. This horizon was encountered thicker (3.0 m+) on the right bank of Olifants River (**Figure 6**) and thins out (0.5 m) towards the river section. A slightly moist, very dense, pinholed, calcretised and ferruginised silty sand horizon underlies the aeolian sand between 0.5 m and 1.5 m (**Table 10**).

Table 10: Test pit description of soils encountered in Zone 1

Test pit No:	Soft to firm, clayey sandy silt. Made ground (m)	Loose to medium dense silty sand. Aeolian	Firm, clayey sandy silt. Alluvium (m) (m)	Very dense, calcretised and ferruginised silty sand. Pedogenic material from aeolian (m)
E-TP01		0.0-3.0+		-
E-TP02		0.0-0.5		0.5-1.5+

Figure 6: Aeolian sand encountered in Zone 1, view from the river section towards the existing right bank canal

5.2.2 Zone 2: Olifants River crossing

No test pits were excavated at the actual river crossing, primarily due to the proximity to the river and the expected high water inflows, but also due to buried services on the left flank. Two test pits were planned on each river bank, i.e. test pits E-TP03 to E-TP06 (**Table 11**). No evidence of shallow bedrock was noted during the site visit (**Figure 7**), but river levels were still relatively high. The local farmer also reported that various materials (building rubble, etc.) have also been dumped into the river.

However, Test pit E-TP07, excavated within the flood plain in proximity to vineyards, indicates a thin layer of made ground encountered as soft to firm, clayey sandy silt from surface to 0.3 m depth, underlain by the firm, clayey sandy silt of alluvial origin. No refusal was encountered, and groundwater seepage was encountered at 2.3 m with water ponding generally observed in the test pit vicinity. It is pertinent that these floodplains had been inundated immediately prior to the test pitting.

Figure 7: Panorama view of the Olifants River crossing, view from E-TP04

The geophysical profiles (Traverse 7 on the right bank and Traverse 8 on the left bank) parallel to the river indicate that the profile on both sides of the river is characterised by a surface resistor which is likely representative of saturated sands, underlain by a conductor, expected to be weathered bedrock, aligned roughly sub-parallel to the surface. These traverses indicated bedrock is likely at depths greater than 10 m to 15 m.

On the right bank, the surface resistor, that is interpreted as **saturated sands** becomes more pronounced towards the west and the east of the traverse and extends to a depth of approximately 15 m. This is underlain by a conductor that is interpreted to be silty sands. The bedrock profile shows some undulations in sub-surface topography and suggest a possible fault – although this is of little significance for the envisaged crossing. Borehole BH E01 intersects this feature but not deep enough to intersect the bedrock interface (note that borehole depths were limited to the maximum expected depth of the syphon only), On the left bank, the surface resistor is more uniform along the length of the traverse. The higher resistivity values are interpreted as saturated sands, which extend to a depth of approximately 10 m. This is underlain by a conductor that is interpreted to be silty sands. The bedrock interface is relatively uniform in sub-surface topography, although some undulations are still evident. Borehole BH E02 intersects the traverse profile along the left bank.

The rotary core boreholes (BH E01 and BH E02) drilled from surface to 7.75 m and 7.95 m respectively confirmed the alluvial origin, with some variation in the soil type.

The geological profile as confirmed by the geophysical tests and the rotary core boreholes can be summarised as below (**Table 11**). Borehole BH E01 was drilled on the right bank, while borehole BH E02 is located on the left bank.

Table 11: Zone 2 - Summary of soil descriptions

Test position No:	Alluvium Loose to medium dense, silty to fine sand. (m)	Alluvium Loose to medium dense, silty sand. (m)	Alluvium. Loose to medium dense, clayey silty sand to silty to clayey sand and soft to firm, clayey sandy silt in E-TP07 (m)	Alluvium. Medium dense, silty to coarse sand (m)	Alluvium. Medium dense, slightly clayey silty sand (m)
Test pits					
E-TP03	Not excavated, immediately next to the river Not excavated, immediately next to the river.				
E-TP04					
E-TP05					
E-TP06					
E-TP07	0.0 – 0.3		0.3-3.0+		
Boreholes					
BH E01	0.0 – 0.15		0.15 – 1.8	1.8 – 7.75+	
BH E02		0.0 – 3.44	3.44 – 5.8	5.8 – 6.0	6.0 – 7.95+

It must be noted that no test pits were excavated on the river banks, although the profile was assumed to be similar to that of E-TP07. Over and above the limited test pit data, the need to consider a depth of approximately 8 m placed emphasis on data obtained from BH E01 and BH E02 and results are therefore based on the borehole data.

Consideration should however be given to the fact that the borehole sample is not completely representative and accurate definition of the horizon boundaries can be difficult, particularly where sample losses occur.

The profile across the river comprise an uppermost aeolian/alluvium described as dry, light yellow brown, silty to fine sand. Roots and organic matter are present. This horizon is thin; with typical thickness of 0.15 m.

The uppermost horizon is underlain by alluvial strata that has a thickness of at least 7.95 m. The strata comprise moist, brown, loose to medium dense silty sand, with an average thickness of 3.3 m, underlain by moist to wet, brown to dark brown, loose to medium dense silty to clayey sand to clayey silty sand that occurs to depths ranging between 1.8 m in BH E01 and 5.8 m in BH E02. The thickness of this layer ranges between 1.65 m and 2.36 m.

This is underlain by alluvium that comprises moist, off-white to light brown, medium dense, silty to coarse sand up to at least the end of the hole (depth 7.75 m in BH E01 and 6 m in BH E02). The thickness ranges between 0.2 m and 5.95 m. No coarse fraction, comprising boulders / cobbles or even gravels, was intersected.

The coarse sand alluvium is underlain by moist, brown to light brown, medium dense, slightly clayey silty sand. This layer is 1.95 m thick (occurring between depths 6 m to 7.95 m) and was evident only in BH E02.

The profile across the river, as obtained by borehole data, corresponds to the geophysical test results that indicated that profile from surface to approximately 10 - 15 m below natural ground level comprises alluvium and quaternary sediments with high to intermediate resistivity values (ranging between 37 to 556+ Ω.m). According to the ERT results, the alluvium is underlain at depth by highly weathered bedrock with low resistivity values of between 0 and 36 Ω.m.

The boreholes were drilled to a maximum depth of 7.95 m and no bedrock was intersected on either side of the river.

5.2.3 Zone 3: Schist outcrop or shallow bedrock

This zone is along the RM2 route to the existing left flank canal, which indicates the start of the Vredendal Diversion. It is mainly on schist bedrock (**Table 12**). The bedrock is generally grey and yellow green, highly weathered, foliated, highly fissile in places, micaceous soft rock schist

(**Figure** 9**8**). The dip of the rocks aligns with the regional trend as the rocks are dipping at approximately 30° in a north-westerly direction.

Table 12: Zone 3 - Profile summary table

Test pit No:	Schist bedrock (m)
E-TP08	0.0-1.5

Figure 8: Schist bedrock encountered in Zone 3, dipping, foliated and fissile in places

5.2.4 Zone 4: Aeolian sand

Zone 4 is located on the Vredendal Diversion route, before the balancing dam. This zone comprises slightly moist, orange-brown, loose to medium dense, pinholed sand of aeolian origin. No refusal was encountered in the excavated test pit (E-TP09) to 3.0 m depth. **Figure 9** indicates deep localised aeolian sand profiles as encountered near the existing left bank canal. Some calcrete nodules (gravel) can be expected across this zone as encountered at the left bank canal.

Figure 9: Zone 4 - localised deep aeolian sand profiles that can be expected across the scheme

5.2.5 Zone 5: Balancing dam

Soil profiles in this dam footprint area largely comprise loose to medium dense, pinholed sand of aeolian origin from surface to an average depth of 1.0 m (**Figure 10**) Aeolian sands are thicker at the centre and towards the southern end of the dam site, and deepest at 2.0 m around E-TP18 (**Table 13**). These transported soils are underlain by dense to very dense, pinholed, calcretised and ferruginised sand, occasionally hardpan calcrete to an average depth of 1.8 m. Generally, the TLB refused on this material across the site. The thickness of this horizon is unconfirmed as it was not possible to intersect the base.

Figure 10: General balancing dam site conditions, showing orange brown aeolian sand cover

Terrace gravels are encountered in the southern corner of the dam site, i.e. in the vicinity of test pits E-TP10 and E-TP16. These gravels underlie the aeolian sand and comprise tightly packed, sub-angular to sub-rounded, fine to coarse, gravel in a matrix of slightly moist, calcretised and ferruginised silty sand with the overall consistency of dense to very dense. The minimum thickness is noted to vary between 0.8 m and 1.6 m.

Table 13: Balancing dam test pit summary description

Test pit No:	Loose to medium dense sand. Aeolian (m)	Dense to very dense, calcretised and ferruginised sand. Pedogenic from aeolian (m)	Calcretised sand with gravels. Pedogenic from terrace gravels (m)
E-TP10	0.0-0.4	2.0-2.3+	0.4-2.0
E-TP11	0.0-1.1	1.1-1.4+	
E-TP12	0.0-1.3	1.3-1.5	
E-TP13	0.0-0.3	0.3-2.0+	
E-TP14	0.0-1.7	1.7-2.6+	
E-TP15	0.0-0.6	0.6-1.4+	
E-TP16	0.0-0.3		0.3-1.1+
E-TP17	0.0-1.3	1.3-1.7+	
E-TP18	0.0-2.0+		

5.2.6 Zone 6: Aeolian sands underlain by calcretised and ferruginised sand (hardpan calcrete)

Zone 6 is the Rising Main Pipeline Route 3 from the balancing dam to the reservoir. Test pits E-TP15 and E-TP16 (**Table 14**) are repeated here. Even though they are on the balancing dam footprint; they are also relevant to the general conditions for the raising main, in particular in the vicinity of the inlet / outlet area.

Table 14: Zone 6 - Rising Main 3 test pit description summary

Test pit No:	Loose to medium dense sand. Aeolian (m)	Dense to very dense, calcretised and ferruginised sand. Pedogenic material from aeolian (m)	Calcretised sand with gravels. Pedogenic from terrace gravels (m)
E-TP15	0.0-0.6	0.6-1.4+	
E-TP16	0.0-0.3		0.3-1.1+
E-TP19	Could not be accessed but E-TP20 expected to be more like E-TP21 and E-TP19 likely to be similar to E-TP13		
E-TP20			

A thin upper layer of loose to medium dense sand is expected as soil cover in this zone, estimated to be between 0.3 m and 0.6 m thick, with an average thickness estimated at 0.4 m. The aeolian sand will typically be underlain by dense to very dense, pinholed, calcretised and ferruginised sand between 0.6 m and 1.4 m depths. Terrace gravels are expected in the vicinity of test pit E-TP16, between 0.3 m and 1.1 m, as described in detail in Section 5.2.5 above.

5.2.7 Zone 7: Colluvium overlying schist bedrock

This area is located in the general area of the north flowing gully, aligned towards the Olifants River, along Rising Main 3 towards the concrete reservoir.

The zone represents the crossing of the drainage channel and the single test pit was excavated on the side slopes of this zone (**Table 15**). A thin upper horizon of transported soils was encountered as loose silty sand to a depth of 0.15 m. The colluvial material is underlain by bedrock, which is generally grey and yellow green, highly weathered, sub-horizontal dipping, foliated, highly fissile schist. The bedrock is largely micaceous very soft to soft rock, but medium hard rock with depths. Bedrock outcrops were encountered in places in this zone. Localised deep aeolian sand areas cannot be ruled out, as patches of sand were observed in this zone.

Table 15: Zone 7 test pit profile summary

Test pit No:	Loose silty sand. Colluvium(m)	Schist bedrock (m)
E-TP21	0.0-0.15	0.15-0.7

5.2.8 Zone 8: Aeolian sands underlain by calcretised and ferruginised sand (hardpan calcrete)

This zone is the last section of the Rising Main 3 route, which connects the balancing dam and the reservoir. Refer to the site layout plans (Dwg 113834-0001-DRG-GG-0001-A to 113834-0001-DRG-GG-0004-A in **Appendix A**.

Generally, a thicker aeolian sand horizon is encountered with thicknesses between 1.7 m and 2.5 m, but the base of the horizon was not intersected. This material comprises orange brown, loose to medium dense, pinholed sand. The aeolian sands are underlain by medium dense, calcretised and ferruginised sand. This horizon was not intercepted in test pit E-TP23 (**Table 16**) due to test pit sidewalls collapsing. At test pit E-TP22 refusal was assumed to have been encountered at 2.0 m, but sidewalls collapsed. It is anticipated that the hardpan calcrete horizon will be intercepted below the 2.5 m depth at test pit E-TP23, as also indicated by the reservoir test pits.

Table 16: Zone 8 - Soil profile summary description

Test pit No:	Loose to medium dense sand. Aeolian (m)	Medium dense, calcretised and ferruginised sand. Pedogenic material from aeolian (m)	Hardpan calcrete
E-TP22	0.0-1.7	1.7-2.0	2+
E-TP23	0.0-2.5		

5.2.9 Zone 9: Concrete reservoir

The reservoir footprint was investigated by excavation of three test pits (**Table 17**). The western portion of the reservoir footprint (E-TP24 and E-TP25) is underlain by aeolian sand with an average thickness of 1.5 m (between 0.7 m and 2.3 m). This material comprises orange brown, loose to medium dense, pinholed sand. Aeolian sand overlies pedogenic material which comprises dense to very dense, calcretised and ferruginised sand. Hardpan calcrete is encountered in the vicinity of test pit E-TP25. The thickness could not be confirmed as it was not possible to intersect the base.

The eastern portion of the reservoir footprint (test pit E-TP24 ADD) is underlain by aeolian sand to 2.2 m depth. The calcrete horizon was not intercepted on this portion of the reservoir due to test pit sidewalls collapsing, which meant the intended depths could not be reached. As for the rising main towards the reservoir, ground conditions comprise loose to medium dense sand.

Table 17: Zone 9 - Concrete reservoir test pit summary

Test pit No:	Loose to medium dense sand. Aeolian (m)	Dense to very dense, calcretised and ferruginised sand. Pedogenic material from aeolian (calcrete) (m)
E-TP24	0.0-0.7	0.7-0.8+
E-TP24 ADD	0.0-2.2+	
E-TP25	0.0-2.3	2.3-2.4+

5.2.10 Zone 10: Aeolian sands underlain by calcrete

This zone mainly comprises aeolian sands (sand dunes), which are underlain by pedogenic material (from aeolian) and occasional hardpan calcrete. The orange and red brown, loose to medium dense sand is generally encountered with an average thickness of 1.0 m. Occasionally these sands may exhibit a maximum thickness of 2.5 m and minimum thickness at 0.3 m. Where no refusal was encountered, deep localised aeolian sands can be expected, i.e. test pits E-TP29 and E-TP34. In such cases, the total thickness of aeolian sands can be regarded as unconfirmed as the base was not intercepted. The pedogenic material is largely dense to very dense, calcretised and ferruginised sand. Refusal is mainly on hardpan calcrete along the route. Difficult excavations and refusal was also encountered on the very dense sand (**Table 18**).

Other localised profiles were also encountered along the route, i.e. including made ground and schist bedrock. Made ground was encountered in the vicinity of E-TP29, from the adjacent road construction. This made ground comprises loose sand to 0.3 m depth, underlain by the aeolian sand. No pedogenic material was encountered within the depth limit of the test pit in this area.

Bedrock was encountered in the vicinity of test pit E-TP27. Bedrock comprises grey and brown, slightly weathered, sub-horizontally dipping, foliated, medium hard rock schist between 0.4 m and 0.5 m, overlain by loose to medium dense aeolian sand.

Table 18: Zone 10 - Summary of soil profiles

Test pit No:	Made ground (m)	Loose to medium dense sand. Aeolian (m)	Dense to very dense, calcretised and ferruginised sand. Pedogenic material from aeolian (calcrete) (m)	Schist bedrock (m)
E-TP26		0.0-0.7	0.7-1.8+	
E-TP27		0.0-0.4		0.4-0.5+
E-TP28		0.0-2.5	2.5+	
E-TP29	0.0-0.3	0.3-2.3+		
E-TP30		0.0-0.9	0.9-1.3+	
E-TP31		0.0-0.55	0.55-0.65+	
E-TP32		0.0-0.9	0.9-1.8+	
E-TP33		0.0-1.3	1.3-1.6+	
E-TP34		0.0-2.5+		
E-TP35		0.0-1.2	1.2-1.5+	
E-TP36		0.0-0.9	0.9-1.0+	
E-TP37		0.0-0.8	0.8-1.2+	
E-TP38		0.0-0.9	0.9-1.1+	
E-TP39		0.0-0.1	0.1-0.5+	
E-TP40		0.0-0.3	0.3-2.0+	
E-TP41		0.0-0.8	0.8-0.9+	

Test pit No:	Made ground (m)	Loose to medium dense sand. Aeolian (m)	Dense to very dense, calcretised and ferruginised sand. Pedogenic material from aeolian (calcrete) (m)	Schist bedrock (m)
E-TP42		0.0-0.3	0.3-0.6+	
E-TP43		0.0-1.1	1.1-1.3+	
E-TP44		0.0-0.8	0.8-1.1+	

5.2.11 Zone 11: Schist outcrop or shallow bedrock

This zone is associated with the north-west flowing drainage channel, which is aligned towards the Olifants River.

The transported soils (aeolian and colluvium) are approximately 0.5 m in thickness, and geologically this soil cover is generally not well-developed in the vicinity of the drainage channel. The sands are loose to medium dense aeolian sand or loose to medium dense, silty sand with gravel of colluvial origin (**Table 20**).

The transported soils are underlain by terrace gravels, which comprise medium dense to very dense gravel in a matrix of calcretised silty sand. This gravel horizon thickness is between 0.3 m and 0.6 m.

Schist outcrops on the left flank of the gully were also observed. The bedrock is encountered as brown, off-white and red, highly weathered, fine grained, occasionally foliated with quartz veins, very soft rock schist (**Figure 11**). It is encountered from surface or at shallow depths of about 1.0 m.

Figure 11: Schist bedrock outcrop in Zone 11

Table 19: Zone 11: Summary of soil profiles

Test pit No:	Loose to medium dense, silty sand with gravel. Colluvium (m)	Loose to medium dense sand. Aeolian (m)	Medium dense to very dense, gravel with calcretised silty sand. Terrace gravel (m)	Schist bedrock (m)
E-TP45	0.0-0.5		0.5-1.1	1.1+
E-TP46		0.0-0.6	0.6-0.9	0.9+
E-TP47				0.0-0.5+

5.2.12 Zone 12: Aeolian sands underlain by calcrete

Zone 12 largely comprises loose to medium dense aeolian sand with an average thickness of 1.1 m, ranging between 0.2 m and 2.5 m. The aeolian sand is underlain by dense to very dense calcretised and ferruginised sand, especially in the area between test pits E-TP57 and E-TP61 (**Table 20**) where this horizon is encountered with an average thickness of 1.2 m, varying between

0.2 m and 2.1 m. Generally, refusal occurred on the well-cemented, very soft rock hardpan calcrete encountered throughout Zone 12.

Table 20: Aeolian sands and pedogenic material summaries for Zone 12

Test pit No:	Loose to medium dense sand. Aeolian (m)	Dense to very dense, calcretised and ferruginised sand. Pedogenic material from aeolian (calcrete) (m)	Refusal on hardpan calcrete (m)
E-TP48	0.0-2.4+		
E-TP49	0.0-2.5+		
E-TP50	0.0-1.4		1.4+
E-TP51	0.0-1.0		1.0+
E-TP52	0.0-0.7		0.7+
E-TP53	0.0-1.5		1.5+
E-TP54	0.0-0.9		0.9+
E-TP55	0.0-0.7		0.7+
E-TP56	0.0-1.1		1.1+
E-TP57	0.0-0.5	0.5-1.9	1.9
E-TP58		0.0-0.2	0.2+
E-TP59	0.0-0.2	0.2-1.5	1.5+
E-TP60		0.0-0.4	0.4+
E-TP61	0.0-0.5	0.5-2.1	2.1+

5.2.13 Zone 13: Schist outcrop or shallow bedrock

This zone is largely on schist bedrock (**Figure 12**) as encountered along the drainage channel. Bedrock here is encountered as outcrop with the road cut at 4.0 m thick (**Table 21**). It is encountered as dark grey, off-white and brown, highly to moderately weathered, laminated, fine grained, very soft to soft rock with abundant quartz veins, micaceous schist bedrock.

Figure 12: Schist bedrock as encountered in Zone 13, exposed in a redundant road cut

Terrace gravels are generally encountered on the upper flank of the drainage channel with a thickness of approximately 0.6 m from surface (**Table 21**). These are encountered as medium dense to dense, angular to sub-angular, fine to medium, gravel in a matrix of slightly moist ferruginised and calcretised silty sand.

Table 21: Zone 13 - Test pit summary description

Test pit No:	Medium dense to dense, gravel with calcretised silty sand. Terrace gravel (m)	Schist bedrock (m)
E-TP62		0.0+
E-TP63	0.0-0.6	0.6-0.75+
E-TP64*		0.0-4.0+

*Note: E-TP64 logged a cut face of a redundant farm road

5.2.14 Zone 14: Aeolian sands underlain by calcrete

Zone 14 is mainly characterised by shallow refusal on the off-white and brown, highly cemented, very soft rock hardpan calcrete. In places the hardpan is observed on surface. The hardpan is encountered at an average depth of 1.1 m (**Table 22**).

Hardpan is largely overlain by dense to very dense, calcrete nodules and honeycomb calcrete, in a matrix of calcretised and ferruginised sand material. This is encountered with an average thickness of 0.7 m, between the depths of 0.4 m and 1.1 m.

Aeolian sand either overlies the dense to very dense pedogenic materials or the hardpan, with an average thickness of 0.4 m.

Table 22: Zone 14 - Summary description of test pit profiles

Test pit No:	Loose to medium dense sand. Aeolian (m)	Dense to very dense, calcretised and ferruginised sand. Pedogenic material from aeolian (calcrete) (m)	Refusal on well cemented hardpan calcrete (m)
E-TP65	0.0-0.2	0.2-0.4+	
E-TP66	0.0-0.5	0.5-1.3	1.3+
E-TP67	0.0-0.5	0.5-1.4	1.4+
E-TP68			0.0-0.3+
E-TP69	0.0-0.2	0.2-2.5	2.5+
E-TP70	0.0-0.2		0.2-0.4+
E-TP71	0.0-0.3		0.3-0.5+
E-TP72	0.0-0.6	0.6-1.3	1.3+
E-TP73	0.0-0.4	0.4-0.6	0.6+
E-TP74		0.0-0.4	0.4-1.2+
E-TP75	0.0-0.7	0.7-1.1	1.1-2.1+
E-TP76		0.0-0.4	0.4-1.2+
E-TP77	0.0-0.1		0.1-0.15+
E-TP78	0.0-0.3	0.3-0.6	0.6+

Test pit No:	Loose to medium dense sand. Aeolian (m)	Dense to very dense, calcretised and ferruginised sand. Pedogenic material from aeolian (calcrete) (m)	Refusal on well cemented hardpan calcrete (m)
E-TP79	0.0-0.35		0.35-0.4+
E-TP80	0.0-0.3		0.3-0.4+
E-TP81			0.0+

5.2.15 Zone 15: Schist outcrop or shallow bedrock

Shallow schist bedrock was encountered as off-white, grey and brown, highly weathered, very soft rock, calcretised schist, from 0.3 m to refusal at 0.4 m (**Figure 13**). The bedrock is overlain by aeolian sands which comprise loose sand to a depth of 0.3 m (**Table 23**).

Table 23: Zone 15 - Test pit profile summary

Test pit No:	Loose sand. Aeolian (m)	Schist bedrock (m)
E-TP82	0.0-0.3	0.3-0.4+

Figure 13: Calcretised schist at the base of the test pit (E-TP82)

A contractor was busy with pipeline construction adjacent to the existing reservoir in this area at the time of investigations. The excavated trenches were assessed and similar ground conditions to the test pit were encountered.

5.3 Laboratory test results

Representative samples were collected for laboratory testing from test pits excavated along the proposed route. Summaries of laboratory results are presented in this section and the detailed results are attached in **Appendix E**.

Note that sample details presented in italics represent the duplicate samples, submitted to the third-party laboratory for quality control purposes.

5.3.1 Foundation indicator results

Summarised foundation indicator test results are presented in **Table 24** below.

Table 24: Summarised foundation indicator results

Test pit no	Depth (m)	Soil composition				GM	Atterberg limits			LS (%)	Activity	USCS	AASHTO class.
		Clay (%)	Silt (%)	Sand (%)	Gravel (%)		LL (%)	PI (%)	WPI (%)				
Aeolian													
E TP 43	0.0-.1.1	1	1	98	0	0.99	0	0	0	0	0	SP-SM	A-3
E TP 48	0.0-2.4	1	1	98	0	0.99	0	0	0	0	0	SP-SM	A-3
E TP 52	0.0-0.6	1	4	95	0	1.27	0	0	0	0	0	SP-SM	A-3
E TP 53	0.0-1.5	2	2	96	0	1.19	0	0	0	0	0	SP-SM	A-3
E TP 66	0.0-0.5	7	18	74	1	0.90	46.0	35	11	10	5.8	SM	A-2-7
E TP 73	0.0-0.4	8	16	73	3	0.89	33	23	11	9	4.9	SC	A-2-6
E TP 28	0.0-2.5	1	2	97	0	1.11	0	0	0	0	0	SP-SM	A-3
E TP 38	0.0-0.9	1	2	97	0	0.99	0	0	0	0	0	SP-SM	A-3
E TP 41	0.0-0.8	1	3	91	5	1.09	0	0	0	0	0	SP-SM	A-3
E TP 33	0.0-1.6	2	6	92	1	0.99	0	0	0	0	0	SP-SM	A-3
E TP09	0.0-3.0	3	2	94	1	1.02	0	0	0	0	0	SP-SM	A-3
E TP 24ADD	0.0-2.2	1	1	87	11	1.23	0	0	0	0	0	SP-SM	A-3
E TP 17	0.0-1.7	1	1	98	0	1.10	0	0	0	0	0	SP-SM	A-3
E TP 17	*0.0-1.30*	*2*	*4*	*93*	*1*	*0.95*	*0*	*0*	*0*	*0*		*SP-SM*	*A-3*
E TP 14	0.0-1.7	1	1	98	0	1.07	0	0	0	0	0	SP-SM	A-3
E TP 11	0.0-1.1	10	8	82	1	0.93	0	0	0	0	0	SM	A-2-4
E TP 18	0.0-2.0	1	1	98	0	1.00	0	0	0	0	0	SP-SM	A-3
E TP 18	*0.0–2.00*	*1*	*2*	*97*	*0*	*0.98*	*0*	*0*	*0*	*0*	*0*	*SP*	*A-3*
E TP 49	*1.1–2.50*	*1*	*4*	*98*	*0*	*1.01*	*0*	*0*	*0*	*0*	*0*	*SP*	*A-3*
E TP 72	*0.0–0.60*	*3*	*13*	*81*	*3*	*0.90*	*0*	*0*	*0*	*0*	*0*	*SM*	*A-2-4*
E TP 15	0.0-1.4	7	7	84	2	0.96	0	0	0	0	0	SM	A-2-4

Test pit no	Depth (m)	Soil composition				GM	Atterberg limits			LS (%)	Activity	USCS	AASHTO class.
		Clay (%)	Silt (%)	Sand (%)	Gravel (%)		LL (%)	PI (%)	WPI (%)				
Alluvium													
E TP 07	0.3-3.0	19	32	43	5	0.62	27.6	14	13	12	0.7	CL	A-6
Pedogenic material													
E TP 35	1.2-1.5	8	3	89	0	0.93	0	0	0	0	0	SP-SM	A-2-4
E TP 45	0.5-1.1	5	11	58	26	1.60	0	0	0	0	0	SM	A-1-B
E TP 57	0.5-1.9	4	10	78	8	1.14	0	0	0	0	0	SM	A-2-4
E TP 59	0.2-1.5	4	13	58	25	1.53	0	0	0	0	0	SM	A-2-4
E TP 61	0.5-2.1	4	13	49	34	1.65	0	0	0	0	0	SM	A-2-4
E TP 78	0.3-0.6	1	44	53	32	1.66	0	0	0	0	0	SM	A-2-4
E TP 33	1.3-1.6	8	5	86	1	0.93	0	0	0	0	0	SM	A-2-4
E TP 10	1.0-2.0	13	22	59	6	0.84	35	23	10	5.4	0.9	SC	A-6
E TP 11	1.1-1.4	2	9	89	0	0.94	0	0	0	0	0	SP-SM	A-2-4
Terrace gravels													
E TP 16	0.3- 0.5	3	1	34	62	2.32	0	0	0	0	0	GP	A-1-A
E TP 46	0.6-0.9	1	1	87	11	1.23	0	0	0	0	0	SM	A-3
E TP 46	0.0-0.6	1	2	89	11	1.87	37	30	7	3	1.2	SM	A-3
E TP 63	0.0-0.6	15	13	24	49	1.79	23	15	8	3	3.8	SC	A-2-4

<u>Legend</u>
GM = Grading modulus
LL = Liquid Limit
PI = Plasticity Index
WPI = Weighted Plasticity Index (PI x % passing the 0.425 mm sieve)
LS = Linear Shrinkage
USCS = Classification of the soil according to the USC classification system
Activity = Potential expansiveness of the soil according to Van der Merwe’s method (Van der Merwe, 1964)

The **aeolian sands** predominantly comprise poorly graded sand (SP), silty sands (SM) and occasionally clayey sands (SC). The sand fraction is high; between 73% and 98%, the clay and silt fractions are generally negligible; clay typically between 1% and 3% but occasionally 7% to 10%, while the silt fraction is also generally between 1% and 3%, but occasionally 4% to 18%. Gravel is generally absent, but where encountered it is between 1% and 3%, but occasionally at 11%. These sands are generally non-plastic, but on rare occasions might prove to be slightly plastic, with a Weighted Plasticity Index (WPI) of 11%. This material generally displays no plasticity, which is indicative of low potential expansiveness, after Van der Merwe (1964).

The single sample of **alluvium** indicates a high fraction of fines; with the silt content at 32% and the clay fraction at 19%. The sand fraction is 43% and the gravel content is low at 5%. The alluvium is considered slightly plastic with the Weighted Plasticity Index of 13% and moderate Liquid Limit at 28%. This material is of low potential expansiveness.

The **pedogenic materials** predominantly comprise poorly graded sand (SP), silty sands (SM) and occasionally clayey sands (SC). The sand fraction is high; between 49% and 89%, the clay fraction is generally negligible; between 1% and 4%, but occasionally between 8% and 13%, the silt fraction is between 3% and 44%. Gravel is generally between 26% and 34%, but occasionally less than 6% to zero. These gravelly sands are generally non-plastic, but on rare occasions might prove to be slightly plastic, with a Weighted Plasticity Index (WPI) of 10%. This material generally displays no plasticity, which is indicative of low potential expansiveness, after Van der Merwe (1964).

The **terrace gravels** comprise silty sands (SM), poorly graded gravels (GP), and occasionally clayey sands (SC). The sand and gravel fractions are high, with the sand content between 24% and 89%, while the gravel fraction is 11% to 62%. It must be remembered that the coarse fraction is not fully included in the laboratory samples, and in truth the coarse fraction can be significantly greater than reflected here. The clay and silt fractions are generally negligible; clay typically between 1% and 3%, but occasionally (outlier) 15%, while the silt fraction is also generally between 1% and 2%, but occasionally 13%. The terrace gravels are generally non-plastic, but on rare occasions might prove to be slightly plastic, with a Weighted Plasticity Index (WPI) of 8% and moderate to high Liquid Limits between 23% and 37%. This material generally displays no or slight plasticity, which is indicative of low potential expansiveness, after Van der Merwe (1964).

5.3.2 Compaction test results

Representative samples were subjected to compaction tests in which the moisture-density relationship was established, with California Bearing Ratio (CBR) tests carried out to determine the suitability of the soils for use in constructing layer works. The results are summarised in Table 25 below.

Table 25: Summarised compaction test results

Test No.	Depth (m)	OMC (%)	MDD (kg-/m3)	Swell (%)	CBR at various densities				COLTO
					90(%)	93(%)	95(%)	98(%)	
Aeolian									
E TP 53	0.0-1.5	11.1	1771	0	3	5	6	9	G10
E TP 28	0.0-2.5	10.5	1821	0	7	8	9	11	G9
E TP 38	0.0-0.9	11.2	1769	0	5	7	9	14	G9
E TP 46	0.0-0.6	9.5	1964	0	11	14	18	24	G8
E TP 33	0.0-1.6	11.3	1650	0	5	7	8	10	G9
E TP09	0.0-3.0	11.6	1859	0	6	8	10	13	G9
E TP 24ADD	0.0-2.2	10.4	1718	0	6	7	8	11	G9
E TP 14	0.0-1.7	10.8	1744	0	8	10	12	15	G8
*E TP 72**	*0.0–0.60*	*11.6*	*1902*	*0*	*6*	*7*	*8*	*9*	*G10*
*E TP 49**	*1.1–2.50*	*11.4*	*1772*	*0*	*9*	*12*	*14*	*19*	*G8*
E TP 15	0.0-1.4	10.4	2023	0	6	9	12	18	G9
Alluvium									
E TP 07	0.3-3.0	10.4	2028	0.80	5	6	7	9	G10
Pedogenic material									
E TP 57	0.5-1.9	9.6	2014	0	9	13	16	22	G8
E TP 45	0.5-1.1	9.6	1912	0	12	15	17	22	G7
E TP 10	1.0-2.0	10	1970	0.76	3	4	5	7	G10
*E TP 61**	*1.1–2.50*	*17*	*1769*	*0*	*9*	*12*	*14*	*18*	*G8*

Legend:
OMC = Optimum moisture content
MDD = Maximum dry density (Mod AASHTO)
Swell = Soaked at 100% Mod AASHTO compaction
COLTO = Committee of Land Transport Officials guidelines (2009)

The **aeolian sands** are characterised by low to moderate maximum dry densities (1650 to 2023 kg/m^3) and moderate optimum moisture contents between 9% and 12%. The CBR swell values are zero. These materials yielded very low or low CBR values at densities typically specified in the field (93 % to 95 %). These sands would only be suitable for construction of engineered fills of low stiffness and classify as G8 or G10 material in accordance with COLTO guidelines (COLTO, 2009), and thus only suitable as selected fill or subgrade road layer works. G10 can alternatively be used for landscaping or be spoiled. .

The single **alluvium** sample indicates a moderate maximum dry density at 2028 kg/m^3 and moderate optimum moisture content at 10%. The CBR swell value is zero. These materials yielded very low or low CBR values at densities typically specified in the field (93 % to 95 %). This material is classified as a G10 according to COLTO guidelines, indicating it is suitable for use in subgrade and engineered fills of low stiffness; alternatively, it can be used for landscaping or spoiled.

The **pedogenic materials** are characterised by low to moderate maximum dry densities (1769 to 2014 kg/m^3) and moderate to high optimum moisture contents between 9% and 17%. The CBR swell values are generally zero, occasionally negligible at 0.76. These materials yielded very low to moderate CBR values at densities typically specified in the field (93 % to 95 %). The pedogenic materials are classified as G7 to G10 according to COLTO guidelines. The G7 material is considered suitable as base coarse in road layer works. G8 or G10 materials are only suitable as selected fill or subgrade road layer works. These materials can consequently only be used in construction of engineered fills of low to moderate stiffness.

5.3.3 Shear strength test results

Summarised shear strength results are presented below in **Table 26**.

Table 26: Summarised shear box test results

Test pit No	Material type	Depth (m)	Apparent Friction Angle (°)	Cohesion (c) (kPa)
Aeolian				
E TP 53	Sand	0.0-1.5	34.2	3.00
E TP 28	Sand	0.0-2.5	34.2	2.00
E TP 38	Sand	0.0-0.9	31.1	3.69
E TP 46	Sand	0.0-0.6	37.1	2.06
E TP 33	Slightly gravelly sand	0.0-1.6	28.4	4.73
E TP 09	Sand	0.0-3.0	38.3	1.7
E TP 24 ADD	Sand	0.0-2.2	35.6	4.05
E TP 14	Sand	0.0-1.7	37.4	0.28
E TP 15	Slightly gravelly sand	0.0-1.4	36.7	7.96
Alluvium				
E TP 07	Clayey sandy silt	0.3-3.0	34.8	10.56
Pedogenic material				
E TP 57	Sandy gravel	0.5-1.9	36.1	21.30
E TP 45	Sandy gravel	0.5-1.1	38.6	35.91
E TP 10	Gravelly sand	1.0-2.0	37.6	15.51

The shear strength test results can be summarised as follows;

- The **aeolian sands** exhibit friction angles between 31° and 39°, and the cohesion values very from 0 kPa up to 8 kPa, which are very low, as might be expected from material that almost entirely comprises sand.

- The single sample of **alluvium** exhibits a friction angle of 35° which is within the usual range that might be expected for such soils and the cohesion value at 11 kPa, which is considered low.
- The **pedogenic materials** show friction angles between 36° and 38°. Cohesion values were typically between 15 kPa and 36 kPa.

5.3.4 Collapse potential test

Undisturbed blocks of the calcretised and ferruginised sands were sampled and submitted for laboratory testing to be subjected to a standard collapse potential test (i.e. soaked at 200 kPa). The results are summarised in **Table 27**.

Table 27: Collapse potential summary results

Test pit No:	Depth (m)	Material type	DD (kg/m^3)	MC (%)	CP (%)
Aeolian					
E TP 33	0.0-1.6	Slightly gravelly sand	1.73	12.1	0.2
E TP 15	0.0-1.4	Slightly gravelly sand	1.74	13.4	0.3
Pedogenic material					
E TP 57	0.5-1.9	Sandy gravel	1.85	12.6	0.6

Legend
DD = In situ dry density
MC = In situ moisture content
CP = Collapse potential (soaked at 200 kPa)

Jennings and Knight (1957) provided guidelines on the interpretation of collapse potential tests, which are summarised in **Table 28**.

Table 28: Guideline values for interpretation of the collapse potential test (after Jennings and Knight, 1957)

Collapse Potential	Severity of the problem
0 % - 1 %	No problem
1 % - 5 %	Moderate trouble
5 % - 10 %	Trouble
10 % - 20 %	Severe trouble
> 20 %	Very severe trouble

The above guidelines indicate that there is “no problem” in terms of severity of collapse potential. However, the soil samples are characterised by a pinholed structure which is known to indicate potentially collapsible conditions (Brink,1996).

5.3.5 Permeability test

The results of permeability tests conducted on remoulded soil samples compacted to approximately 98% Proctor are summarised in **Table 29**.

Table 29: Permeability summary results

Test pit No:	Material type	Depth (m)	Permeability (cm/s)
Aeolian			
E TP 09	Sand	0.0-3.0	1.34×10^{-5}
E TP 53	Sand	0.0-1.5	1.93×10^{-3}
E TP 46	Sand	0.0-0.6	4.81×10^{-3}
E TP 28	Sand	0.0-2.5	1.93×10^{-3}
E TP 17	Sand	0.0-1.7	5.71×10^{-3}
E TP 14	Sand	0.0-1.7	5.42×10^{-3}
E TP 15	Slightly gravelly sand	0.0-1.4	9.74×10^{-7}
Pedogenic material			
E TP 10	Gravelly sand	1.0-2.0	5.19×10^{-8}

Das (2002) summarised typical values for the coefficient of permeability (k, cm/sec) in relation to the degree of permeability, based on laboratory results in **Table 29**.

Table 30: Typical values for coefficient of permeability, after Das (2002)

Coefficient of permeability (k, cm/sec)	Degree of permeability
$>10^{-1}$	Very highly permeable
$10^{-1} > k > 10^{-3}$	High to moderately permeable
$10^{-3} > k > 10^{-5}$	Low permeability
$10^{-5} > k > 10^{-7}$	Very low permeability
$<10^{-7}$	Virtually impermeable

The sand materials of **aeolian origin** generally exhibit permeabilities between 5.71×10^{-3} and 1.34×10^{-5} cm/s, which are considered low permeability. The slightly gravely sand material proved to be of very low permeability at 9.74×10^{-7} cm/s.

The single sample of **pedogenic material** exhibits a permeability of 5.19 x 10^{-8} cm/s, which is considered impermeable due to presence of gravel and calcrete nodules.

5.3.6 Chemical tests (pH and conductivity)

The conductivity of the soil has a profound influence on the rate of corrosion of buried metallic objects. Based on significance of soil resistivity on corrosiveness, Duligal (1996) provides the following table (**Table 31**) for evaluation of the conductivity of soil.

Table 31: Guideline values for interpretation of soil conductivity (Duligal, 1996)

Soil conductivity (mS/m)	Soil resistivity (Ohm.cm)	Corrosively classification
More than 50	0 – 2000	Extremely corrosive
25 – 50	2000 – 4000	Very corrosive
20 – 25	4000 – 5000	Corrosive
10 – 20	5000 – 10000	Mildly corrosive
Less than 10	>10000	Not generally corrosive

The chemical test results comprising pH and conductivity are listed in **Table 32**.

Table 32: Chemical test summary results

Test pit No	Depth (m)	pH	Conductivity (mS/m)	Corrosivity classification
Aeolian				
E TP 46	0.0-0.6	9.5	25.0	Corrosive
E TP 48	0.0-2.4	7.6	7.0	Not generally corrosive
E TP 53	0.0-1.5	7.3	28.0	Very corrosive
E TP 38	0.0-0.9	6.9	24.0	Corrosive
E TP 41	0.0-0.8	6.7	15.0	Mildly corrosive
E TP 17	0.0-1.7	6.9	2.0	Not generally corrosive
E TP 14	0.0-1.7	7.4	5.0	Not generally corrosive
E TP 73	0.0-0.4	7.4	8.0	Not generally corrosive
E TP 18	0.0-2.0	7.2	16.0	Mildly corrosive
E TP 72	*0.0-2.4*	*6.2*	*13.9*	*Mildly corrosive*
E TP 76	*0.0–2.5*	*5.5*	*6.2*	*Not generally corrosive*
E TP 15	0.0-1.4	8.8	13.0	Mildly corrosive
Alluvium				
E TP 07	0.3-3.0	8.2	14	Mildly corrosive
Colluvium				
E TP 25	*0.9-2.2*	*6.0*	*7.9*	*Not generally corrosive*

Test pit No	Depth (m)	pH	Conductivity (mS/m)	Corrosivity classification
Pedogenic material				
E TP 33	1.3-1.6	7.8	3.0	Not generally corrosive
E TP 35	1.2-1.5	7.5	13.6	Mildly corrosive
E TP 57	0.5-1.9	8.8	40.7	Very corrosive
E TP 59	0.2-1.5	8.3	71.9	Extremely corrosive
E TP 78	0.3-0.6	7.4	8.0	Not generally corrosive
E TP 11	1.1-1.4	7.8	6.5	Not generally corrosive
E TP 51	*0.5-1.2*	*8.6*	*77.5*	*Extremely corrosive*
Terrace gravels				
E TP 16	0.3- 0.5	5.6	19.0	Mildly corrosive
E TP 16	*0.4-1.8*	*5.9*	*4.9*	*Not generally corrosive*
E TP 46	0.6-0.9	6.5	18.3	Mildly corrosive
E TP 63	0.0-0.6	5.6	11.3	Mildly corrosive
E TP 78	*0.5-1.5*	*6.9*	*18.6*	*Mildly corrosive*

Corrosiveness of a soil will increase when water is present in the soil or when fluctuating water levels are present. In addition, the amounts of salts in the soil increase the corrosiveness, which will typically be encountered in pedogenic soil. Furthermore, based on Evans' guideline (1977) a soil pH less than 6 indicates serious corrosion potential of steel and concrete. A pH less than 4.5 indicates rapid metal corrosion and serious risks to common construction materials, including some stainless-steel grades.

According to the soil conductivity guideline values in **Table 31** (Duligal, 1996) and the results in Table 32, the results can be summarised as follows:

- The **aeolian sands** are not corrosive, with the exception of the area in the vicinity of E-TP76 where the results indicate a pH of 5.5. Conductivity values of between 2 mS/m and 25 mS/m indicate the materials to be not generally corrosive to corrosive.
- The **alluvium** is not corrosive with the pH of just above 8 and conductivity value of 14 mS/m indicating the material to be mildly corrosive.
- The **colluvium** is not generally corrosive with the pH of 6 and conductivity value of about 8 mS/m.
- The **pedogenic materials** are not corrosive according to the pH results, but the conductivity values of between 3 mS/m and 76 mS/m indicate the soils to be not generally corrosive to extremely corrosive.
- **Results for the terrace gravels** indicate there are localised areas with pH of less than 6, which is regarded as corrosive. The conductivity values of between 4 mS/m and 19 mS/m indicate the materials to be not generally corrosive to mildly corrosive.

The apparent contradiction in the corrosiveness classifications from correlations with pH values and soil conductivity is noted.

Soil conductivity relates directly to salinity (Pathak and Rao, 1998). Salinity usually refers to the presence of soluble salts in the soil. Soil pH may affect the solubility of salts and soil moisture content. More alkaline soil will have a lesser amount of soluble salts (Provin et al., 2012). This means that low soil pH values, should have higher soluble salts content and therefore high soil conductivity.

It is recommended that additional chemical testing be conducted to investigate the corrosiveness of the soils.

5.3.7 Dispersivity

Selected samples were subjected to a suite of tests to assess the dispersivity, including the Double Hydrometer, Pinhole Test, the Crumb Test, as well as Sodium Adsorption Ratio (SAR) and Extractable Sodium Percentage (ESP) chemical tests. No single test is deemed entirely reliable in confirming the dispersivity of a soil, and for this reason a suite of tests is usually conducted. Results are summarised below in **Table 33**.

Table 33: Summarised dispersivity results

Test pit No:	Material type	Depth (m)	Double hydrometer (%)	Pinhole test	Crumb test	Sodium Adsorption Ratio (SAR)	Extractable Sodium Percentage (ESP)
Aeolian							
E TP 53	Sand	0.0-1.5	0.0	*	Non-Dispersive	2.86	8.14
E TP 28	Sand	0.0-2.5	0.0	*	Non-Dispersive	2.78	7.89
E TP 38	Sand	0.0-0.9	0.0	*	Non-Dispersive	2.71	7.64
E TP 46	Sand	0.0-0.6	0.0	*	Non-Dispersive	2.74	7.76
E TP 33	Slightly gravelly sand	0.0-1.6	0.0	*	Non-Dispersive	3.94	10.73
E TP09	Sand	0.0-3.0	25.0	*	Non-Dispersive	2.50	6.86
E TP 24ADD	Sand	0.0-2.2	0.0	*	Non-Dispersive	3.02	8.62
E TP 14	Sand	0.0-1.7	0.0	*	Non-Dispersive	2.09	5.08
E TP 11	Sand	0.0-1.1	0.0	*	Non-Dispersive	3.22	9.21
E TP 49	*Sand*	*1.1–2.50*					
E TP 72	*Sand*	*0.0–0.60*					
E TP 15	Gravelly sand	0.0-1.4	0.0	*	Non-Dispersive	6.18	5.28
Alluvium							
E TP 07	Clayey sandy silt	0.3-3.0	30.7	Dispersive	Dispersive	3.33	7.03
Pedogenic material							
E TP 57	Sandy gravel	0.5-1.9	20.0	*	Non-Dispersive	16.96	14.25
E TP 45	Sandy gravel	0.5-1.1	19.5	*	Non-Dispersive	7.71	9.04

Test pit No:	Material type	Depth (m)	Double hydrometer (%)	Pinhole test	Crumb test	Sodium Adsorption Ratio (SAR)	Extractable Sodium Percentage (ESP)
E TP 10	Gravelly sand	1.0-2.0	19.0	Slightly Dispersive	Slightly Dispersive	27.99	29.94
Terrace Gravels							
E TP 16	*Gravel in silty sand matrix*	*0.3- 0.5*	*0.0*	Slightly Dispersive	Slightly Dispersive	6.17	7.95

* The Crumb Test is not applicable for samples with 12% or less particles passing 0.005mm and having a plasticity index less than or equal to 8

In assessing the results, the following tables are used i.e. **Table 34**, **Table 35** and **Table 36**.

Table 34: Criteria for evaluation of degree of dispersion from double hydrometer test (after Bell and Maud, 1994)

Percent dispersion (%)	Degree of dispersion
<30	Non-dispersive
30 to 50	Intermediate
>50	Dispersive

Table 35: Criteria for evaluation of degree of dispersion from ESP results (after Gerber, 1983)

Extractable Sodium Percentage ESP (%)	Degree of dispersion
<15	Highly dispersive
6 to 15	Dispersive
4 to 6	Marginal
<4	Non-dispersive

Table 36: Criteria for evaluation of degree of dispersion from SAR results

Sodium Adsorption Ratio SAR (%)	Degree of dispersion
<1.5	Non-dispersive
1.5 to 2	Intermediate
>2	Dispersive

Based on the laboratory results and evaluation tables above, the following comments can be made with regards to dispersivity.

The **aeolian sands** are considered non-dispersive based on the pinhole test results, double hydrometer and crumb tests. However, the SAR results indicate that materials are dispersive, and the ESP result indicate marginal to dispersive for aeolian sands.

Double hydrometer results indicate that the **alluvial material** is of intermediate dispersivity. However, all the other suite of tests show the material is dispersive.

The **pedogenic materials** are non-dispersive according to double hydrometer results while pinhole and crumb test indicate non-dispersivity to slightly dispersive results. However, SAR and ESP indicate dispersive to highly dispersive results for the pedogenic materials.

Terrace gravels are also non-dispersive according to double hydrometer results while pinhole and crumb test indicate non-dispersivity to slightly dispersive results. However, SAR and ESP indicate dispersive results.

It should be noted that there are some apparent contradictions in the determined dispersivity of soils as per different laboratory tests. The chemical tests also indicate a similar contradiction likely due to the presence of soluble salts in the soil. Further testing is recommended to confirm the dispersivity of the soils.

5.3.8 In-situ moisture content

Various samples were taken from different horizons and tested for their in-situ moisture content. **Table 37** below compares the in-situ moisture content at the time of the geotechnical investigation with the optimum moisture content (obtained from compaction testing).

Table 37: In-situ moisture conditions along the proposed Ebenhaeser Scheme

Test pit No:	Depth (m)	Material type	In-situ moisture content (%)	OMC available from CBR testing (%)
Aeolian				
E TP 43	0.0-.1.1	Sand	1.9	
E TP 48	0.0-2.4	Sand	1.4	
E TP 52	0.0-0.6	Sand	3.2	
E TP 53	0.0-1.5	Sand	1.6	11.1
E TP 46	0.0-0.6	Sand	4.6	9.5
E TP 66	0.0-0.5	Sand	5	
E TP 73	0.0-0.4	Sand	4	
E TP 28	0.0-2.5	Sand	1.2	10.5
E TP 38	0.0-0.9	Sand	2.2	11.2
E TP 41	0.0-0.8	Sand	4.1	

Test pit No:	Depth (m)	Material type	In-situ moisture content (%)	OMC available from CBR testing (%)
E TP 33	0.0-1.6	Slightly gravelly sand	6.5	11.3
E TP09	0.0-3.0	Sand	1.6	11.6
E TP 24ADD	0.0-2.2	Sand	0.5	10.4
E TP 17	0.0-1.7	Slightly gravelly sand	2.5	
E TP 14	0.0-1.7	Sand	5.4	10.8
E TP 11	0.0-1.1	Sand	5.5	
E TP 18	0.0-2.0	Sand	1.8	
E TP 72	0.0-0.6	Sand	4.7	11.6
E TP 15	0.0-1.4	Slightly gravelly sand	5.4	10.4
Alluvium				
E TP 07	0.3-3.0	Clayey sandy silt	16.3	10.4
Pedogenic material				
E TP 35	1.2-1.5	Sand	6.5	
E TP 45	0.5-1.1	Gravel in silty sand matrix	8	9.6
E TP 57	0.5-1.9	Gravelly sand	6.3	9.6
E TP 59	0.2-1.5	Gravelly sand	8.8	
E TP 40	1.1-2.5	Gravelly sand	1.3	
E TP 61	0.5-2.1	Gravel in silty sand matrix	7.4	17.0
E TP 78	0.3-0.6	Gravel in sand matrix	11	
E TP 33	1.3-1.6	Sand	*11.8*	11.3
E TP 10	1.0-2.0	Gravelly sand	*11.6*	10.0
E TP 11	1.1-1.4	Sand	5.4	
Terrace Gravels				
E TP 16	0.3- 0.5	Gravel in silty sand matrix	1.7	
E TP 46	0.6-0.9	Gravel in silty sand matrix	1.1	
E TP 63	0.0-0.6	Gravel in silty sand matrix	2.8	

Table 37 indicates that most samples indicate lower in-situ moisture content compared to the optimum moisture content.

5.4 Field test results

5.4.1 Dynamic Cone Penetrometer (DCP) results

The dynamic cone penetrometer results (DCP) are summarised in **Table 38** below.

Table 38: DCP test summary results along the gravity pipeline

Test No	Total depth (m)	Depth where 30 < PR < 75 (mm/blow) Loose	Depth where 15 < PR < 30 (mm/blow) Medium dense	Depth where 5 < PR < 15 (mm/blow) Dense	Remarks
E-TP43	1.0	0.0-0.6	0.8-1.0	0.6-0.8	No refusal
E-TP49	1.0	0.0-1.0	0.9-1.0		
E-TP50	1.0	0.0-0.9	0.9-1.0		
E-TP53	1.0	0.0-8	0.8-1.0		

Where PR = penetration rate

Results obtained from the DCP test gives a rough indication of the consistency of the soils based on the penetration rate (Table 38). This relationship is regarded as a guide for non-cohesive soils.

The results indicate that the aeolian sands are generally loose, medium dense and dense and reflect material stiffness increasing with depth.

5.4.2 Electrical Resistivity Tomography (ERT) results

Two ERT traverses at selected positions on either side of the Olifants River crossing at the Ebenhaeser Scheme were conducted to investigate typical ground conditions. The traverses for this particular site are referred to as Traverse 7 and Traverse 8 as per the ERT Report contained in **Appendix F**.

The ERT Models along each traverse are presented in **Figure 14** and **Figure 15** below.

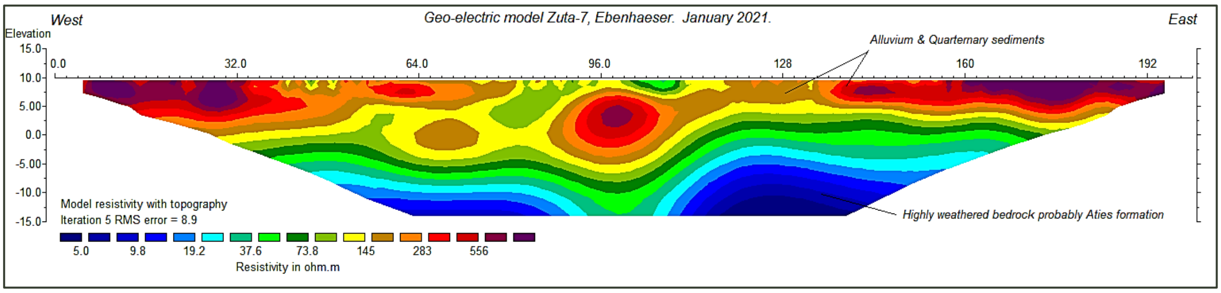


Figure 14: ERT Model along Traverse 7

The ERT model along the right bank (Traverse 7) indicates that the profile from surface to approximately 15 m below natural ground level comprise alluvium and quaternary sediments with high to intermediate resistivity values (ranging between 37 and 556+ Ω.m). This is underlain at depth by highly weathered bedrock with low resistivity values of between 0 and 36 Ω.m. The irregular profile might indicate a possible fault. This is unconfirmed, but in any event does not have a bearing on the envisaged structure.

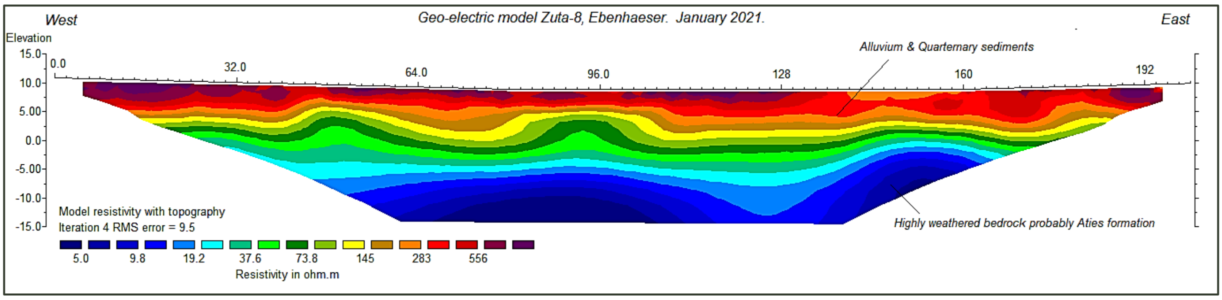


Figure 15: ERT Model along Traverse 8

The ERT model along the left bank (Traverse 8) indicates that the profile from surface to approximately 10 m below natural ground level comprise alluvium and quaternary sediments with high to intermediate resistivity values (ranging between 37 and 556+ Ω.m). This is underlain by highly weathered bedrock with low resistivity values of between 0 and 36 Ω.m. The weathered bedrock appears much more uniform along the left bank.

5.4.3 Standard Penetration Test (SPT) results

For each of the boreholes, the SPT N-values have been presented in **Table 39**.

Table 39: SPT N-Values summary

Borehole number	Depth (m)	Description	SPT N-Value
BH E01	1.50 – 1.95	silty to clayey sand, ALLUVIUM	7
	2.81 – 3.26	silty to coarse sand, ALLUVIUM	7
	4.31 – 4.76	silty to coarse sand, ALLUVIUM	8
	5.83 – 6.28	silty to coarse sand, ALLUVIUM	29
	7.30 – 7.75	silty to coarse sand, ALLUVIUM	11
BH E02	1.50 – 1.95	silty sand, ALLUVIUM	14
	2.99 – 3.44	silty sand, ALLUVIUM	14
	4.50 – 4.95	clayey silty sand, ALLUVIUM	13
	6.00 – 6.45	slightly clayey silty sand, ALLUVIUM	18
	7.50 – 7.95	slightly clayey silty sand, ALLUVIUM	18

The SPT values range between 7 and 29. According to the correlations presented in **Table 7** the consistency of the silty to coarse sand alluvium varies between loose and medium dense. The consistency of the silty and clayey silty sand alluvium is medium dense.

6 Geotechnical considerations

The following geotechnical aspects must be considered in the design and construction of the proposed Ebenhaeser Scheme.

Elements of the scheme’s geological and geotechnical considerations are discussed separately in sections below and the general considerations are also grouped together.

6.1 General considerations

6.1.1 Compressible and collapsible soils

The red or orange brown, very loose to medium dense, aeolian sand encountered across the scheme is known to be potentially collapsible (Brink,1985). However, the collapse potential test results indicate no problems are expected on site with regards to the aeolian sand and pedogenic materials.

The pinholed soil structure observed in the aeolian sand during fieldwork is characteristic of collapsible fabric which can lead to differential settlement of the soils under load. The soft to firm, clayey sandy silt, alluvium encountered along the Retshof Diversion at the flanks of Olifants River are likely to be compressible under load. These soil deposits are normally found near river mouths, floodplains and drainage channels, as is the case on site.

Further laboratory testing such as consolidation testing should be considered to confirm the potential collapsibility of the soils or alternatively considerations to be taken for the design of foundations.

6.1.2 Dispersive and erodible soils

The suite of laboratory tests conducted to test the dispersivity of the soils indicates that the materials encountered on site are non-dispersive to highly dispersive.

It should be noted that there are some apparent contradictions in the determined dispersivity of soils as per different laboratory test. The chemical tests also indicate a similar contradiction; likely due to the presence of soluble salts in the soil. Further testing is recommended to investigate the dispersivity of the soils.

6.1.3 Expansiveness in soils

Based on the laboratory test results, the materials encountered on site generally display no or slight plasticity, which is indicative of low potential expansiveness, after Van der Merwe (1964).

6.1.4 Unstable or steep natural slopes

The scheme is generally characterised by flat or gently sloping topography except along the Retshof and Vredendal Diversion routes where steep natural slopes are encountered. For the remainder of the pipeline route no evidence of unstable natural slopes was observed.

6.1.5 Seismicity

As per Section 4.3, the scheme is located outside a known area of natural seismic activity and outside regions of mining-induced seismic activity, and is considered a non-seismic activity zone. As such, no specific seismic design requirements, other than normal structural design requirements, are required (SANS 10160-4: 2011).

6.1.6 Excavation considerations

The excavation of the materials encountered along the corridor of the proposed scheme has been assessed in terms of SANS 1200D (1988) guidelines, which classifies excavations as follows:

Soft excavation shall be excavation in material which can be efficiently removed or loaded without prior ripping by any of the following plant:

- A bulldozer with a mass of approximately 22 tons, (which includes the mass of a ripper if fitted) and an engine developing approximately 145 kW at the flywheel; or
- A tractor-scraper unit with a mass of approximately 28 tons and an engine developing approximately 245 kW at the flywheel, pushed during loading by a bulldozer.
- A track-type front-end loader with a mass of approximately 22 tons and an engine developing approximately 140 kW at the flywheel.

Intermediate excavation shall be excavation (excluding soft excavation) in material which can be efficiently ripped by a bulldozer with a mass of approximately 35 tons when fitted with a single tine ripper and an engine developing approximately 220 kW at the flywheel.

Hard excavation shall be excavation (excluding boulder excavation) in material which cannot be efficiently ripped by a bulldozer. This type of excavation generally includes excavation in material such as formations of unweathered rock, which can be removed only after blasting.

The details are provided under each element as part of considerations.

6.1.7 Groundwater conditions

Groundwater seepage was encountered at 2.3 m at test pit E-TP07. However, the entire river crossing area was under water during the fieldwork, as it is located on the floodplain and was inundated immediately prior to the fieldwork.

Depending on the construction method favoured for the syphon, pumping of groundwater at the Olifants River crossing may be necessary or even the construction of a coffer dam.

Where no water seepage was encountered, the possibility of intersecting groundwater cannot be ruled out as the presence of ferruginised sand suggests the occurrence of fluctuating water level. The presence of calcrete along the route indicates the likelihood of the presence of a shallow water table or possible lateral seepage of groundwater.

6.2 Retshof and Vredendal Diversions - Rising Main Pipeline 1 and 2 respectively

It is understood that all Rising Main pipelines (1-3) and the gravity pipeline will be buried below the natural ground level. The pipes are understood to be High-Density Polyethylene (HDPE) with steel pipes used at road and river crossings.

6.2.1 Geological profile

Zoning of the pipeline route, by sub-dividing into approximate sections of similar geological conditions, has already been carried out and has been described previously (Sections 5.2). This is not generally repeated here but is broadly summarised in **Table 40**.

Table 40: Summary of geological profiles along Rising Main 1 and 2

Zone	Summary of geological profiles
1	Alluvium and aeolian sand underlain by calcretised and ferruginised sand
2	Alluvial materials
3	Schist outcrop or shallow bedrock
4	Aeolian sand

6.2.2 Excavation

The test pit profiles have been used to estimate the general depths of the anticipated excavation classes for Rising Main 1 and 2 pipelines, which is presented in **Table 41**.

Table 41: Excavation summary along RM1 and RM2

Test pit No:	Soft and Intermediate excavation classification (m)	Hard excavation classification (m)
E-TP01	0.0-3.0+*	
E-TP02	0.0-1.5+*	
E-TP03 to E-TP06	Not excavated, immediately next to the river	
E-TP07	0.0-3.0+	
E-TP08		0.0+
E-TP09	0.0-2.5+	

* No refusal, profiled exposed cut faces near the existing right bank canal

Soft excavations in terms of SANS 1200D: Earthworks, (SANS, 1988), are to be expected in aeolian sand and alluvium to an average depth of 2.5 m, varying between 1.5 m and 3 m. This is based on the excavated test pit and the profiled cut faces. Shallow schist bedrock and outcrops can be regarded as hard excavations, as encountered in Zone 3.

6.2.3 Sidewall stability in trenches

Rising Main 1 and 2 will be buried in the ground and as such the sidewall trench stability is in reference to temporary cut slopes.

The loose to medium dense aeolian sand and soft to firm alluvium might be susceptible to trench sidewall instabilities if trenches are left open for too long. Shallow groundwater is expected at the river crossing.

Zone 2 (chainage 300 to 500) and Zone 3 (chainage 720 to 1 000) traverses soft to medium hard schist bedrock dipping between 30° and 40° towards the south west (**Figure 16)**. The trench cut slopes are to be battered to a steeper angle than the dip of the strata.

Direct shear testing of remoulded samples of the various soils was conducted, and the results have been presented previously. The testing yielded a general range of friction angles between 30° and 40°.

If the temporary battered slopes cannot be achieved, owing to, for example, space constraints, then suitable lateral support, such as shoring, will have to be considered for these temporary cut slopes.

Sidewall Instability was a common occurrence in the excavated test pits. These unstable conditions serve to highlight the potential risks of slope instabilities that will be associated with the upper soil horizons during excavations.

Regular inspection of cut faces by a geotechnically-competent person will be essential during construction.

Figure 16: Exposed schist dipping between 30° and 40° as encountered along the existing left bank canal

6.2.4 Corrosiveness

The laboratory results suggest that the alluvium at Rising Main 1 is mildly corrosive (**Table 42**). It should be noted that this test is only indicative of the aggressiveness of the soil and that in view of the test results the buried steel and concrete elements in soil should be protected.

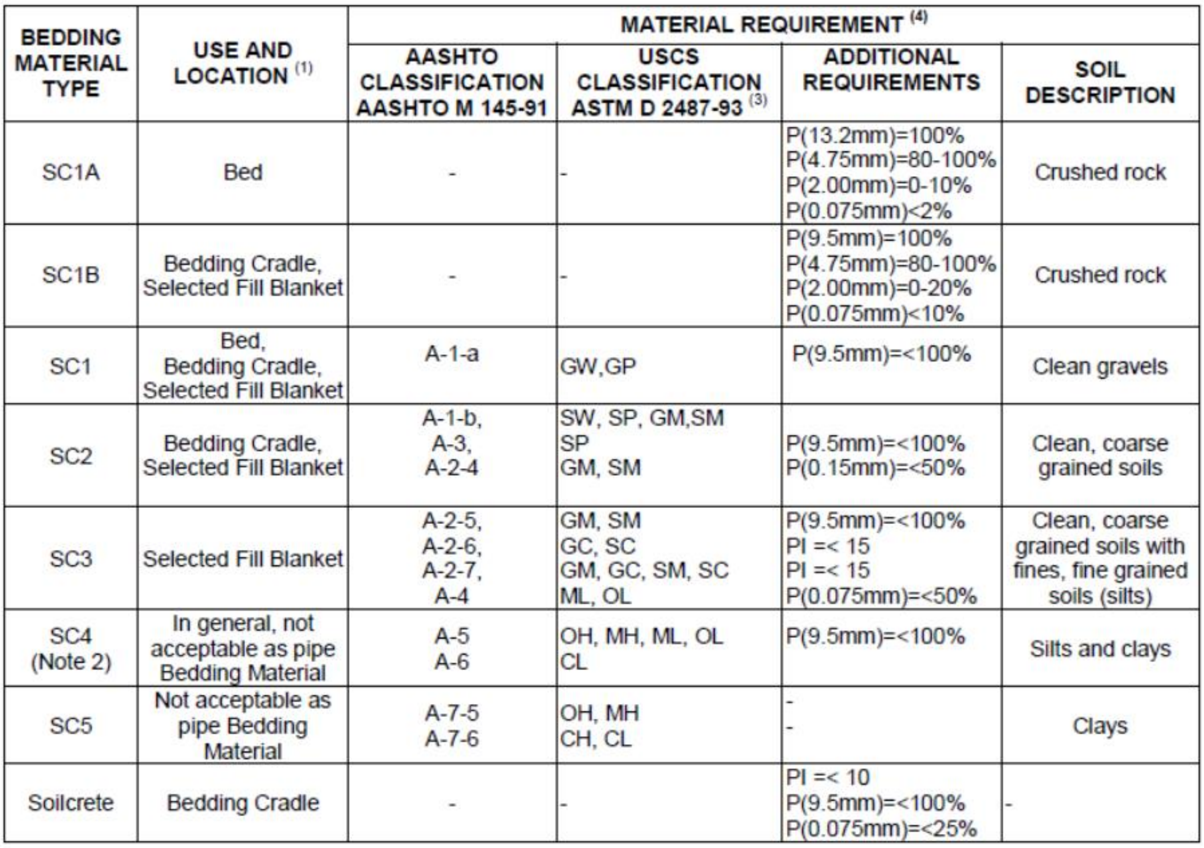
Table 42: Corrosiveness of soil along Rising Main 1 and 2 route

Test pit No	Depth (m)	pH	Conductivity (mS/m)	Corrosivity classification
Alluvium				
E TP 07	0.3-3.0	8.2	14	Mildly corrosive

6.2.5 Suitability of excavated material for use as selected backfill

Table 43 below summarises the suggested soil material types classified according to AASHTO M-145 as a function of pipe bedding type. In addition, the material was also classified according to SANS 1200 LB and 1200 DB.

Table 43: Bedding material type requirements as per SANS 1200 DB



BEDDING MATERIAL TYPE	USE AND LOCATION (1)	MATERIAL REQUIREMENT (4)			
		AASHTO CLASSIFICATION AASHTO M 145-91	USCS CLASSIFICATION ASTM D 2487-93 (3)	ADDITIONAL REQUIREMENTS	SOIL DESCRIPTION
SC1A	Bed	-	-	P(13.2mm)=100% P(4.75mm)=80-100% P(2.00mm)=0-10% P(0.075mm)<2%	Crushed rock
SC1B	Bedding Cradle, Selected Fill Blanket	-	-	P(9.5mm)=100% P(4.75mm)=80-100% P(2.00mm)=0-20% P(0.075mm)<10%	Crushed rock
SC1	Bed, Bedding Cradle, Selected Fill Blanket	A-1-a	GW,GP	P(9.5mm)=<100%	Clean gravels
SC2	Bedding Cradle, Selected Fill Blanket	A-1-b, A-3, A-2-4	SW, SP, GM,SM SP GM, SM	P(9.5mm)=<100% P(0.15mm)=<50%	Clean, coarse grained soils
SC3	Selected Fill Blanket	A-2-5, A-2-6, A-2-7, A-4	GM, SM GC, SC GM, GC, SM, SC ML, OL	P(9.5mm)=<100% PI =< 15 PI =< 15 P(0.075mm)=<50%	Clean, coarse grained soils with fines, fine grained soils (silts)
SC4 (Note 2)	In general, not acceptable as pipe Bedding Material	A-5 A-6	OH, MH, ML, OL CL	P(9.5mm)=<100%	Silts and clays
SC5	Not acceptable as pipe Bedding Material	A-7-5 A-7-6	OH, MH CH, CL	- -	Clays
Soilcrete	Bedding Cradle	-	-	PI =< 10 P(9.5mm)=<100% P(0.075mm)=<25%	-

The re-use of in situ material as bedding material for Rising Main 1 and 2, according to AASHTO M-145, SANS 1200LB and 1200DB, is summarised in **Table 44** below.

Table 44: Assumed re-use of in-situ material for RM 1 and RM2 pipelines

Material origin	Material Classification	Plasticity Index Range	Grading Modulus Range	Percent clay	Assumed re-use
Alluvium	CL A-6	14	0.62	19%	Not suitable as bedding and backfill material
Aeolian sand	SP-SM A-3	0	1.02	3%	Suitable as bedding material and selected fill blanket, i.e. SC2 bedding material types.

Note:

1. Pipe material assumed to be HDPE (High Density Polyethylene) – Assumed to be a flexible pipe.
2. Assumed requirements for bedding: Selected granular fill for bedding cradle and selected fill for the blanket.
3. According to SANS 1200 LB, selected granular material shall be granular, non- cohesive nature, singularly graded between 0.6 mm and 19 mm, free-draining and has a compatibility factor not exceeding 0.4.
4. According to SANS 1200 LB, selected fill material shall be material that has a PI not exceeding 6, free from vegetation and lumps and stones of diameter exceeding 30 mm.
5. Backfill shall contain little or no organic material, excludes stones of average dimension exceeding 150 mm, and be placed without significant voids and so compacted as to avoid significant settlement. Material containing more than10%of rock or hard fragments that are retained on a 50 mm aperture sieve is unsuitable. Material containing large clay lumps that do not break under the action of compaction equipment shall be deemed unsuitable for backfill. In areas subject to loads from road traffic and other specified areas, backfill shall have a PI not exceeding 12 and a minimum CBR of 15% at specified density if the backfill is to be placed in the upper 150 mm of the subgrade, and a minimum CBR of 7% if the backfill is to be placed lower in the subgrade.

6.2.6 Olifants River crossing

The river crossing is expected to comprise a syphon, and the discussion points that follow are tailored on that assumption. The discussion therefore does not address all possibilities, for instance, the discussion does not consider alternatives such as a bridge crossing, for example.

6.2.6.1 Ground conditions

Based on boreholes BH E01 and BH E02, deep alluvial soils are expected, coupled with high water levels. The alluvial soils extend to at least 8 m below NGL (the maximum depths of the boreholes).

The base of the alluvial deposits was not intersected, and neither the depth of the underlying bedrock nor the bedrock condition is confirmed. The envisaged syphon will not extend deeper than 8 m, hence the termination depth of the respective boreholes. Within this ‘zone’ the alluvial deposits might be considered relatively uniform, i.e. comprising fine-grained sediments. Lateral variation must be expected, however, in this active river environment. No coarse fraction (gravel / cobble / boulders) was recorded in the two boreholes, but a coarse fraction of scattered cobbles / possible boulders cannot be completely discounted.

The relatively uniform profile within the upper 8 m implies that differential settlement is not anticipated

6.2.6.2 Water table

This river crossing will be within the active river channel and appropriate measures to deal with high flows and even flooding would be required. Construction methodologies will have to deal with high water levels, saturated soils and water inflows even during periods of normal river flow.

6.2.6.3 Stability of excavations

Unsupported excavations within the river section, within these saturated alluvial sands, will be prone to collapse. This was borne out by the single test pit (E-TP07) excavated in proximity to the river crossing, which exhibited failure of the sidewalls. In general, the alluvial sands encountered in the boreholes (BH E01 and BH E02) must be considered to be saturated and therefore prone to collapse.

All excavations will therefore either require battering or will require support, such as shoring, or combinations thereof. It is doubtful whether battering of slopes to safe angles only will be practical, as these slopes would of necessity be very flat, and would be subject to continual collapse.

No decisions have yet been taken regarding the favoured method of construction, but consideration of stabilisation of excavations, and lateral support requirements, are some of the implications of a decision on the favoured construction methodology.

6.2.6.4 Excavation

The alluvial sands to a depth of at least 8 m below NGL (as encountered in the two boreholes) will classify as ‘soft excavations’ in accordance with SANS 1200 D. The profile might include occasional cobbles / boulders, even though the two boreholes did not intersect such materials and the selected excavation methods must be able to deal with a coarser fraction.

6.2.7 R363 road crossing

Rising Main 2 will be crossing the provincial road R363 between the balancing dam and Olifants River.

The closest test pit indicates loose to medium dense aeolian sand to 3.0 m with sidewalls collapsing during the investigation. These soils are susceptible to trench sidewall instabilities if trenches are left open for too long. These temporary cut faces must be cut to safe angles, and / or shored.

It is understood that this road crossing will comprise a steel pipe. At this stage, a method of construction has not been determined. Options for this road crossing would include a cut-and-cover option or pipe-jacking. Considering the low traffic levels on the R363, it is likely that a cut-and-cover option would be optimal. No detailed information is available about the diameter of the steel pipe, founding levels or the construction method at this stage.

It is recommended that this section is re-visited after subsequent refinements in the design during the detailed design phase to determine whether additional deeper geotechnical investigations are required.

6.3 Balancing Dam

The geology of the dam site has been detailed under Section 5.2.5 and is zoned as Zone 5.

6.3.1 Founding considerations

It is understood that the balancing dam will be a lined earth fill structure.

The test pits provide insight into the expected founding conditions; from which required excavation depths can be deduced. Because the dam is to be lined, the foundation does not have to prescribe to permeability criteria. The founding for the dam can be estimated using a dam centreline e.g. E-TP11 (1.4 m), E-TP17 (1.7 m), E-TP18 (2.0 m) and E-TP14 (2.6 m).

The base of the balancing dam will largely be the dense to very dense, calcretised and ferruginised sand with occasional hardpan calcrete. Adequate bearing capacity may be obtained from these materials to an average depth of 1.8 m, i.e. between 1.4 m and 2.6 m.

Concerns are on the southern corner of the site, i.e. around E-TP10 and E-TP16 where terrace gravels are encountered. These gravels are calcretised, ferruginised and cemented to dense or very dense consistencies. However the risk regarding foundation permeability or a seepage path into the dam cannot be ruled out. Consideration is that the balancing dam should be founded below terrace gravels on the calcretised and ferruginised sand. The terrace gravels also pose stability concerns on this southern side of the dam and this is discussed in detail in Section 6.3.5 below.

6.3.2 Permeability

As stated, the entire balancing dam will be fully lined and neither the permeability of the founding materials of the embankment, nor of the wider basin are therefore defining material parameters. At the time of the investigation, however, the need for lining had not been resolved, and permeability tests were conducted to inform this design choice. Permeability test results have been included above (Section 5.3.5), but the results relevant to the balancing dam are summarised below (**Table 45**).

Table 45: Summary of the dam site permeability

Test pit No:	Material type	Depth (m)	Permeability (cm/s)
Aeolian			
E TP 17	Sand	0.0-1.7	5.71×10^{-3}
E TP 14	Sand	0.0-1.7	5.42×10^{-3}
E TP 15	Slightly gravelly sand	0.0-1.4	9.74×10^{-7}
Pedogenic material			
E TP 10	Gravelly sand	1.0-2.0	5.19×10^{-8}

The aeolian sands at the balancing dam location generally yielded a permeability of 5×10^{-3} cm/sec, which is too pervious for use as earthfill embankment material. It is noted that a single sample did yield 9×10^{-7} cm/sec, which would have been more acceptable in terms of utilisation in a homogeneous embankment.

The pedogenic gravelly sands also proved to be sufficiently impervious (5×10^{-8} cm/s) for consideration within a homogeneous embankment.

The bulk of the available materials however comprise the aeolian sands and it would not be feasible to consider either construction of an earthfill embankment with these materials, or water storage within the basin, without some form of lining, or a design that might include a zoned embankment.

It is pertinent that a nearby dam was being rehabilitated at the time of the investigation. A lining was being installed.

6.3.3 Stability of natural slopes

The site of the balancing dam is characterised by relatively flat or gentle slopes. There are no steep slopes defining the potential basin area that are cause for concern in terms of slope stability issues.

6.3.4 Excavation

The refusal depth of the TLB during the test pitting exercise can be used as an indication of the depth to which soft excavation can be expected to extend (**Table 46**).

Table 46: Balancing Dam - Average depths of anticipated excavation

Test pit No:	Soft and Intermediate excavation classification depth (m)	Hard excavation classification depth (m)
E-TP10	0.0-2.3	2.3+
E-TP11	0.0-1.4	1.4+
E-TP12	0.0-1.2	1.2+
E-TP13	0.0-2.0	2.0+
E-TP14	0.0-2.6	2.6+
E-TP15	0.0-1.4	1.4+
E-TP16	0.0-1.1	1.1+
E-TP17	0.0-1.7	1.7+
E-TP18	0.0-2.0	

Based on the excavated test pits at the dam site, the *soft excavations* in terms of SANS 1200D: Earthworks, (SANS, 1988), are to be expected in aeolian sand, terrace gravel and the pedogenic materials to an average depth of 1.7 m, varying between 1.1 m and 2.6 m. Refusal on hardpan and schist bedrock can be classified as *hard excavation* in terms of SANS 1200D: Earthworks, (SANS, 1988).

It is not envisaged that deep excavations, i.e. beyond the depth of refusal (3.0 m), will be required, with the possible localised exception at the dam intake / outlet.

6.3.5 Excavation stability

Construction of the balancing dam will typically not require any deep or significant excavations. It is only at the intake / outlet works that temporary excavations might be of interest. Test pit sidewalls collapsed during the field investigations particularly where deep aeolian sands are encountered. The stability of excavations during the dam construction may therefore be compromised and shoring or battering of excavations will be required.

The terrace gravels encountered on the southern side of the dam site present a particular concern in terms of stability of excavations. Where the excavations intersect this horizon, there is a likelihood that ravelling, and spalling will occur within these gravel soils. This can result in undercutting of the overlying strata, and an associated risk of slope failure. The stability of these horizons will be further compromised when wet. Excavation within these gravels also carries the risk that removal of the coarser fraction can result in further disturbance of the stratum, and due care is called for in these instances. Further slope battering or shoring may be required in such instances.

6.3.6 Corrosiveness

The laboratory results suggest that the aeolian sand, pedogenic materials and terrace gravels at the Balancing Dam site are generally non-corrosive to mildly corrosive (**Table 47**). Due to mild corrosivity, buried steel and concrete elements in soil will need to be protected.

Table 47: Corrosiveness of the materials encountered at the Balancing Dam site

Test pit No	Depth (m)	pH	Conductivity (mS/m)	Corrosivity classification
Aeolian				
E TP 17	0.0-1.7	6.9	2.0	Not generally corrosive
E TP 14	0.0-1.7	7.4	5.0	Not generally corrosive
E TP 18	0.0-2.0	7.2	16.0	Mildly corrosive
E TP 15	0.0-1.4	8.8	13.0	Mildly corrosive
Pedogenic material				
E TP 11	1.1-1.4	7.8	6.5	Not generally corrosive
Terrace gravels				
E TP 16	0.3- 0.5	5.6	19.0	Mildly corrosive

6.3.7 Construction materials

Considering that the balancing dam will be a lined structure, the embankment would not have to be considered as a conventional water-retaining earth structure, but rather as an earth structure that would primarily be required to support the lining system.

The aeolian sands and pedogenic materials encountered in the dam footprint are classified as G7 to G10 according to COLTO guidelines. The G7 material is considered suitable as base coarse in road layer works. G8 or G10 materials are only suitable as selected fill or subgrade road layer works. Alternatively, they need to be spoiled or can be used for landscaping. These materials would only be suitable for construction of engineered fills of low stiffness in layerworks.

The general material suitability for use in embankments is summarised in **Table 48**.

Table 48: Suitability of in-situ material for embankment construction

Material origin	Main constituents	USCS	Suitability for use in embankment
Aeolian	Mainly sand	SM, SP and occasional SC	Medium desirability; low compressibility, but good shear strengths when compacted
Alluvium	Clayey sandy silt	CL	Poor to fair suitability

Material origin	Main constituents	USCS	Suitability for use in embankment
Terrace gravels	Variable sand gravel mainly, sometimes minor clay, silt	Mainly SM and some GP and SC	Medium to fair suitability Good to fair shear strengths and low compressibility
Pedogenic materials	Highly variable, mainly blends of silts, sands, also gravels	SM, SP and occasional SC	Medium desirability; low compressibility, but good shear strengths when compacted

6.3.8 Other considerations

Overhead powerlines traverse the dam site and consideration will need to be given to whether these powerlines need to be relocated, or not. It is to be noted that there are currently two transmission lines crossing the planned balancing dam site, but that a third line is also planned, which will run between the two existing lines.

6.4 Rising Main Pipeline 3 between the dam and the reservoir

Rising Main Pipeline 3 constitutes Zone 6 to 8 in Section 5.2, which provides detailed geological profiles and zonation.

6.4.1 Excavation

The refusal depth in the test pits (**Table 49**) during the fieldwork can be used as an estimate for excavation classifications.

Table 49: Average depths of anticipated excavation for the Rising Main pipeline 3

Test pit No:	Soft and Intermediate excavation classification depth (m)	Hard rock excavation classification depth (m)
E-TP15	0.0-1.4	1.4+
E-TP16	0.0-1.1	1.1+
E-TP19 and E-TP20	Not excavated due to accessibility constrains	
E-TP21	0.0-0.7	0.7+
E-TP22	0.0-2.0	2.0+
E-TP23	0.0-2.5+	

Based on the excavated test pits the rising main route can be classified as *soft excavations* in terms of SANS 1200D: Earthworks, (SANS, 1988), to an average depth of 1.3 m. Shallow schist bedrock is encountered around the gully and the general refusal on hardpan can be classified as *hard excavation* in terms of SANS 1200D.

6.4.2 Sidewall stability in trenches

The ground conditions for the Rising Main 3 route will traverse three geological zones as described in Section 5.2 above, and as such three different trench stability scenarios are to be expected.

Zone 6 is characterised by a thin layer of loose to medium dense sand, estimated to be encountered between 0.3 m and 0.6 m with an average thickness of about 0.4 m. This horizon is generally underlain by the very dense pedogenic material. The aeolian sand horizon which is generally susceptible to sidewall collapse, is shallow and no major concerns are expected in this zone in terms of stability of trenches.

No stability concerns in trenches are envisaged In **Zone 7**. The colluvium material is very shallow and is underlain by the sub-horizontal dipping schist bedrock.

A thicker aeolian sand horizon is encountered in **Zone 8** with the average thickness of 2.1 m. This material comprises loose to medium dense sand, which is susceptible to trench sidewall instabilities It is recommended that all soils in this zone are either battered back at an angle of 30° or flatter or shored.

6.4.3 Corrosiveness

Table 50 summarises the pH and conductivity results for the Rising Main 3 pipeline route.

Table 50: Corrosiveness of materials along the Rising Main 3 pipeline route

Test pit No	Depth (m)	pH	Conductivity (mS/m)	Corrosivity classification
Aeolian				
E TP 15	0.0-1.4	8.8	13.0	Mildly corrosive
Terrace gravels				
E TP 16	0.3- 0.5	5.6	19.0	Mildly corrosive
*E TP 16**	*0.4-1.8*	*5.9*	*4.9*	*Not generally corrosive*

The laboratory results suggest that the aeolian sand and terrace gravels are generally non-corrosive to mildly corrosive. Due to mild corrosiveness, special consideration (protection) should be given in the design against the deterioration of buried steel and concrete elements in soil.

6.4.4 Suitability of excavated material for use as selected backfill

Table 51 summarises material classification and the suggested re-use potential for in-situ materials according to AASHTO M-145, SANS 1200LB and 1200DB.

Table 51: RM 3 pipeline: Assumed material re-use of the in-situ material

Material origin	Material Classification	Plasticity Index Range	Grading Modulus	Percent clay	Assumed re-use
Terrace gravels	GP A-1-a	0	2.32	3%	Suitable as bedding material and selected fill blanket, i.e. SC1 bedding material types.

Note:

1. Pipe material assumed to be HDPE (High Density Polyethylene) – Assumed to be a flexible pipe.
2. Assumed requirements for bedding: Selected granular fill for bedding cradle and selected fill for the blanket.
3. According to SANS 1200 LB, selected granular material shall be granular, non- cohesive nature, singularly graded between 0.6 mm and 19 mm, free-draining and has a compatibility factor not exceeding 0.4.
4. According to SANS 1200 LB, selected fill material shall be material that has a PI not exceeding 6, free from vegetation and lumps and stones of diameter exceeding 30 mm.
5. Backfill shall contain little or no organic material, excludes stones of average dimension exceeding 150 mm, and be placed without significant voids and so compacted as to avoid significant settlement. Material containing more than10%of rock or hard fragments that are retained on a 50 mm aperture sieve is unsuitable. Material containing large clay lumps that do not break under the action of compaction equipment shall be deemed unsuitable for backfill. In areas subject to loads from road traffic and other specified areas, backfill shall have a PI not exceeding 12 and a minimum CBR of 15% at specified density if the backfill is to be placed in the upper 150 mm of the subgrade, and a minimum CBR of 7% if the backfill is to be placed lower in the subgrade.

The **terrace gravels** are suitable for bedding material and selected fill blanket, however sourcing of these may be a challenge at they are only encountered around the dam inlet area.

Aeolian sands are generally suitable as bedding materials and selected fill blanket across the scheme.

6.5 Concrete reservoir

The geological profile for the reservoir site is discussed in detail under Section 5.2.9. Reference is made to this section, but the summaries are not repeated here.

6.5.1 Founding considerations

A reinforced concrete slab foundation is a common approach for small reservoirs. Relatively small differences in soil settlement under the slab can initiate and develop cracks in the slab. The concrete slab should therefore ideally be founded on competent material.

The concrete reservoir should be founded on the very dense calcretised and ferruginised sand (hardpan calcrete) to allow for adequate bearing capacity. The perimeter of the reservoir site can be subdivided into shallow hardpan on the western side and deeper pedogenic material on the east and southern sides. This is likely to require a cut of 2.5 m or deeper to found on the hardpan. Alternatively, a compacted backfill below the structure could be considered on the east and southern side of the reservoir.

6.5.2 Excavation

The test pit profiles have been used to estimate the general depths of the anticipated excavation classes, which are presented in **Table 52**.

Table 52: Excavation summary at the reservoir site

Test pit No:	Soft and Intermediate excavation classification depth (m)	Hard excavation classification depth (m)
E-TP23*	0.0-2.5	
E-TP24 ADD	0.0-2.2	
E-TP25	0.0-2.4	2.4
E-TP24	0.0-0.8	0.8+

* Part of RM3 but added here for discussion purposes

The *soft excavations* in terms of SANS 1200D: Earthworks, (SANS, 1988), are expected on aeolian sand to an average depth of 2.0 m. The western side of the reservoir has shallow hardpan at less than a meter and deeper towards the east and south. *Hard excavations* can be expected in the hardpan calcrete which underlies the aeolian sands.

6.5.3 Excavation stability

Should the design approach require cutting to 2.5 m depth for founding the reservoir on hardpan, this will create slope stability concerns in the overlying aeolian sands.

The test pit sidewalls collapsed during the field investigations. The stability of excavations during the reservoir construction may be compromised and shoring or battering of excavations will be required.

6.5.4 Corrosiveness

The soils at the reservoir site were not specifically tested for pH and conductivity, but the general corrosiveness conditions on the aeolian sands along the entire scheme indicates that *not generally corrosive* to *corrosive* conditions are to be expected on buried steel and concrete elements. Special consideration needs to be taken for protection of the steel and concrete used in building the reservoir.

6.6 Gravity pipeline

6.6.1 Suitability of excavated material for use as selected backfill

Considerations in **Table 53** should be noted for assumed re-use of in situ materials, according to AASHTO M-145, SANS 1200LB and 1200DB.

Table 53: Gravity pipeline: Assumed re-use of the in situ material

Material origin	Material Classification	Plasticity Index Range	Grading Modulus Range	Percent clay	Assumed re-use
Aeolian sands	SP, SM, occasionally SC A-3, A-2-4, A-2-6 and A-2-7	Mainly 0, occasionally 23-35	0.89-1.27	1% - 3% occasionally 7% - 10%,	Mainly suitable as bedding material and selected fill blanket, i.e. SC2 and SC3 bedding material types. Not suitable in occasional cases where high PI content was encountered.
Pedogenic materials (ferruginised and calcretised sand and calcrete)	SP, SM A-2-4, A-1-b,	0	0.93 1.66	1% - 4% occasionally 8%	Suitable as bedding material and selected fill blanket, i.e. SC2 and SC3 bedding material types.
Terrace gravels	SM, SC A-3, A-2-4	Mainly 0, occasionally 15	1.23 – 1.79	< 3, occasionally 15%	Suitable as bedding, bedding material and selected fill blanket, i.e. SC1 to SC3 bedding material types.

Note:

1. Pipe material assumed to be HDPE (High Density Polyethylene) – Assumed to be a flexible pipe.
2. Assumed requirements for bedding: Selected granular fill for bedding cradle and selected fill for the blanket.
3. According to SANS 1200 LB, selected granular material shall be granular, non- cohesive nature, singularly graded between 0.6 mm and 19 mm, free-draining and has a compatibility factor not exceeding 0.4.
4. According to SANS 1200 LB, selected fill material shall be material that has a PI not exceeding 6, free from vegetation and lumps and stones of diameter exceeding 30 mm.
5. Backfill shall contain little or no organic material, excludes stones of average dimension exceeding 150 mm, and be placed without significant voids and so compacted as to avoid significant settlement. Material containing more than10%of rock or hard fragments that are retained on a 50 mm aperture sieve is unsuitable. Material containing large clay lumps that do not break under the action of compaction equipment shall be deemed unsuitable for backfill. In areas subject to loads from road traffic and other specified areas, backfill shall have a PI not exceeding 12 and a minimum CBR of 15% at specified density if the backfill is to be placed in the upper 150 mm of the subgrade, and a minimum CBR of 7% if the backfill is to be placed lower in the subgrade.

6.6.2 Excavation

The refusal depth (**Table 54**) of the TLB during the test pitting exercise can be used as an indication of the depth to which soft excavation can be expected to extend.

Table 54: Gravity pipeline: Average depths of anticipated excavation

Test pit No:	Soft and Intermediate excavation classification depth (m)	Hard excavation classification depth (m)
E-TP26	0.0-1.8	1.8+
E-TP27	0.0-0.5	0.5+
E-TP28	0.0-2.5	2.5+
E-TP29	0.0-2.5	
E-TP30	0.0-1.3	1.3+
E-TP31	0.0-0.65	0.65+
E-TP32	0.0-1.8	1.8+
E-TP33	0.0-1.6	1.6+
E-TP34	0.0-2.5	
E-TP35	0.0-1.5	1.5+
E-TP36	0.0-1.0	1.0+
E-TP37	0.0-1.2	1.2+
E-TP38	0.0-1.1	1.1+
E-TP39	0.0-0.5	0.5+
E-TP40	0.0-2.0	2.0+
E-TP41	0.0-0.9	0.9+
E-TP42	0.0-0.6	0.6+
E-TP43	0.0-1.3	1.3+
E-TP44	0.0-1.1	1.1+
E-TP45	0.0-1.1	1.1+
E-TP46	0.0-0.9	0.9+
E-TP47		0.0+
E-TP48	0.0-2.4	2.4+
E-TP49	0.0-2.5	2.5+
E-TP50	0.0-1.4	1.4+
E-TP51	0.0-1.0	1.0+
E-TP52	0.0-0.7	0.7+
E-TP53	0.0-1.5	1.5+
E-TP54	0.0-0.9	0.9+
E-TP55	0.0-0.7	0.7+
E-TP56	0.0-1.1	1.1+
E-TP57	0.0-1.9	1.9+

Test pit No:	Soft and Intermediate excavation classification depth (m)	Hard excavation classification depth (m)
E-TP58		0.0+
E-TP59	0.0-1.5	1.5+
E-TP60		0.0+
E-TP61	0.0-2.1	2.1+
E-TP62		0.0+
E-TP63	0.0-0.75	0.75+
E-TP64		0.0+
E-TP65	0.0-0.4	0.4+
E-TP66	0.0-1.3	1.3+
E-TP67	0.0-1.4	1.4+
E-TP68		0.0+
E-TP69	0.0-2.5	2.5+
E-TP70	0.0-0.4	0.4+
E-TP71	0.0-0.5	0.5+
E-TP72	0.0-1.3	1.3+
E-TP73	0.0-0.6	0.6+
E-TP74	0.0-1.2	1.2+
E-TP75	0.0-2.1	2.1+
E-TP76	0.0-1.2	1.2+
E-TP77		0.0+
E-TP78	0.0-0.6	0.6+
E-TP79	0.0-0.4	0.4+
E-TP80	0.0-0.4	0.4+
E-TP81		0.0+
E-TP82	0.0-0.4	0.4+

The *soft excavations* in terms of SANS 1200D: Earthworks, (SANS, 1988), are to be expected on aeolian sand, alluvium and terrace gravels to an average depth of 1.2 m with pockets of deep sand profiles to a maximum depth of 2.5 m. The *hard excavations*, as per SANS 1200D, are encountered in hardpan calcrete and schist bedrock.

At the time of compiling the geotechnical report the invert level for the gravity pipeline was not finalised by the design team. Hence comparison between the invert level and refusal has not been included.

6.6.3 Sidewall stability in trenches

The trench batter angles recommended for the material types encountered (SP, SM, SC and CL) is 30° (assessed to a 3.0 m depth). However, as the sidewalls were occasionally collapsing on aeolian sand, flatter batter angles may be necessary. Where groundwater is encountered in the excavation, the batters may also require further flattening. Cognisance should also be given to areas where terrace gravels and calcrete nodules were noted in the ground profile, which may result in unstable sidewalls during the excavation process.

6.6.4 Corrosiveness

It is understood that the gravity pipeline will mainly be a High-Density Polyethylene (HDPE) with steel pipes used at the three gully crossings.

Table 55: Corrosiveness of the materials encountered along the gravity pipeline route

Test pit No	Depth (m)	pH	Conductivity (mS/m)	Corrosivity classification
Aeolian				
E TP 46	0.0-0.6	9.5	25.0	Corrosive
E TP 48	0.0-2.4	7.6	7.0	Not generally corrosive
E TP 53	0.0-1.5	7.3	28.0	Very corrosive
E TP 38	0.0-0.9	6.9	24.0	Corrosive
E TP 41	0.0-0.8	6.7	15.0	Mildly corrosive
E TP 73	0.0-0.4	7.4	8.0	Not generally corrosive
*E TP 72**	*0.0-2.4*	*6.2*	*13.9*	*Mildly corrosive*
*E TP 76**	*0.0–2.5*	*5.5*	*6.2*	*Not generally corrosive*
Pedogenic material				
E TP 33	1.3-1.6	7.8	3.0	Not generally corrosive
E TP 35	1.2-1.5	7.5	13.6	Mildly corrosive
E TP 57	0.5-1.9	8.8	40.7	Very corrosive
E TP 59	0.2-1.5	8.3	71.9	Extremely corrosive
E TP 78	0.3-0.6	7.4	8.0	Not generally corrosive
E TP 51	*0.5-1.2*	*8.6*	*77.5*	*Extremely corrosive*
Terrace gravels				
E TP 46	0.6-0.9	6.5	18.3	Mildly corrosive
E TP 63	0.0-0.6	5.6	11.3	Mildly corrosive
E TP 78	*0.5-1.5*	*6.9*	*18.6*	*Mildly corrosive*

The laboratory results suggest that the aeolian sand, pedogenic materials and terrace gravels along the gravity pipeline corridor are non-corrosive to extremely corrosive (**Table 55)**. It should be noted that these tests are only indicative of the aggressiveness of the soil and that in view of the test results special consideration should be given in the design against the deterioration of buried steel and concrete elements in soil.

6.7 Construction materials

The geotechnical investigations have considered the suitability of the in-situ soils for use in pipeline construction and also for the balancing dam. The investigations have however not focused on sourcing materials such as coarse aggregates for concrete, e.g. for the construction of the reservoir.

6.7.1 In-situ material suitability as selected backfill

Aeolian sands and pedogenic materials are generally suitable as bedding materials across the scheme, and selected fill blanket, i.e. SC1 and SC3 bedding material types according to SANS 1200 LB and 1200 DB.

The **terrace gravels** are suitable for bedding material and selected fill blanket. However, sourcing these materials may be a challenge at they are only encountered in localised areas (i.e. in zone 5, zone 11 and zone 13) along the scheme.

Alluvial material, as encountered along the Rising Main 1 pipeline route, is considered unsuitable as bedding and backfill material.

6.7.2 Potential material sources for layer works

The **aeolian sands** would only be suitable for construction of engineered fills of low stiffness. These sands classify as G8 or G10 material, in accordance with COLTO guidelines, and thus are only suitable as selected fill or subgrade road layer works and engineered fills of low stiffness. G10 material can alternatively be used for landscaping or spoiled.

The **alluvium** is classified as a G10 according to COLTO guidelines, indicating that it is suitable for use in subgrade and engineered fills of low stiffness. Alternatively, it can be used for landscaping or spoiled.

The **pedogenic materials** are classified as G7 to G10 according to COLTO guidelines. The G7 material is considered suitable as base coarse in road layer works. G8 or G10 are only suitable as selected fill or subgrade road layer works.

6.7.3 Coarse aggregates for concrete

It is unlikely that a new hard rock source will be developed purely for sourcing of crushed stone for construction of the concrete reservoir, and other minor areas of concrete structures. Due to the limited quantities required, coarse aggregates for construction purposes will likely need to be sourced from a commercial source, for example Cape Lime (Pty) Ltd., which produces crushed stone of G1-G7 and is located in Vredendal.

Due to unfavourable physical and mechanical properties of schist, that include low strengths and platy mineral alignment, this rock type is not considered to be acceptable to be used for the manufacture of coarse aggregate. No other bedrock was encountered along the scheme except for the schist.

6.7.4 Fine aggregates

Various potential sources of natural sand were encountered along the route, including areas underlain by aeolian sands. Exploitation of the various sources of natural sands would be dependent on overcoming environmental limitations. Should these options still be favoured, it would be necessary to confirm the various sand deposits are compliant in terms of meeting specifications. Fine aggregate (sand) for concrete manufacture is also likely to be sourced from commercial sources.

7 Conclusions and recommendations

7.1 Excavation stability

The test pit sidewalls largely collapsed in the very loose to medium dense aeolian sands during the field investigations. The stability of excavations during construction may be compromised and shoring or battering of excavations will be required. Attention must be paid to the presence of seepage and terrace gravels.

As part of safe practice during construction, stability assessment would be required for deeper excavations left open for longer periods. These assessments should be conducted by a suitably qualified and experienced geotechnical practitioner.

7.2 Soil corrosiveness

The soils along the Ebenhaeser scheme corridor are generally non-corrosive to extremely corrosive. This indicates that special considerations need to be taken for the steel and concrete, in particular for the concrete reservoir, inlet and outlet structure for the balancing dam, and where used along the pipelines, e.g. fittings.

The HDPE pipe that is proposed for the scheme generally has an excellent corrosion resistance Therefore, no corrosion problems are likely to be encountered along the pipelines.

7.3 Other factors

It is recommended that foundation excavations at the balancing dam and the concrete reservoir be inspected by an experienced geotechnical engineer or engineering geologist prior to placing of concrete or earthfill respectively to ensure that suitable founding material has been obtained in the excavations. This is an important aspect because the investigation findings rely on point information (test pits) and localized variations may be revealed in the excavations.

The scheme is located outside natural seismic activity, and outside regions of mining-induced and natural seismic activity. The area is considered a non-seismic activity zone and as such, no specific seismic design requirements other than normal structural design requirements are required.

Groundwater seepage was only encountered along the Retshof Diversion. However, the possibility of intersecting seepage elsewhere cannot be completely ruled out, as the presence of pedogenic materials suggests the occurrence of fluctuating water levels.

The suite of laboratory tests conducted to test the dispersivity of the soils indicates that the materials encountered on site are non-dispersive to highly dispersive.

The aeolian sands, pedogenic materials and terrace gravels along the route are suitable as backfill materials with the alluvium encountered along Rising Main 1 being unsuitable.

The Concrete Reservoir should be founded on the very dense, calcretised and ferruginised sand (hardpan calcrete) to allow for adequate bearing capacity. The ground conditions at the reservoir can be subdivided into shallow hardpan on the western side and deeper pedogenic material on the eastern and southern sides. This is likely to require a cut of 2.5 m or deeper to found on the hardpan. Alternatively, compacted backfill below the structure could be considered on the eastern and southern sides of the reservoir.

Soft excavations in terms of SANS 1200D are to be expected in aeolian sand, alluvium and terrace gravels. Hard excavations, as per SANS 1200D, are encountered in hardpan calcrete and schist bedrock.

7.4 Additional investigations

Investigations conducted to date are sufficient for the current feasibility-phase of the project, and no additional investigations are identified at this stage.

The possibility that the detailed design phase might require further geotechnical inputs cannot be excluded, however.

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9 Limitations of report

1. Zutari Ground Engineering has prepared this report for use by Zutari design colleagues as well as our Client, the DWS. The report has not been prepared for use by parties other than Zutari and DWS.

2. There are always some variations in subsurface conditions across a site due to geological conditions that cannot be defined fully even by exhaustive investigation. Hence, it is possible that the measurements and values obtained from sampling and testing during the investigation may not represent the extremes of conditions which exist within the site. The precision with which subsurface conditions are identified depends on the method of investigation, the frequency and recovery of samples, the method of sampling, and the uniformity of the subsurface conditions. Subsurface conditions at locations other than the investigation positions may vary from conditions at the investigation locations.

3. Further, subsurface conditions, including groundwater levels can change over time. The groundwater conditions described in this report refer only to those observed at the place and time of observation noted in the report. These conditions may vary seasonally or as a consequence of construction or agricultural activities in the area. This should be borne in mind, particularly if the report is used after a protracted delay or a period of protracted climatic conditions.

4. Should conditions exposed at the site during subsequent investigation or construction works vary significantly from those provided in this report, we request that Zutari Ground Engineering be informed and have the opportunity to review any of the findings or conclusions of this report. It is highly recommended that during construction the site conditions be inspected by a representative of Zutari Ground Engineering to confirm the geotechnical interpretations in this design.

5. Unless otherwise stated, this design does not address potential environmental hazards, or groundwater contamination that may be present.

6. The investigation logs represent the subsurface conditions at the specific test locations only. Boundaries between zones on the logs are not often distinct, but rather are transitional and have been interpreted. The soil / rock descriptions in this report are based on commonly accepted

methods of classification and identification employed in geotechnical practice, as stated. Classification and identification of soil involves judgement, and Zutari Ground Engineering infers accuracy in the classification and identification methods to the extent that is common in current geotechnical practice, and within the limitations of the ground investigation that was performed.

7. It is recommended that further geotechnical input from Zutari Ground Engineering should be sought as the project moves into the next phase to confirm that the geotechnical assumptions made in this report are compatible with the structural performance requirements and are being applied appropriately.

Appendix A

Site Layout Drawings

TP ID	CO-ORDINATES ON WG84_Lo19	
	Y	X
E-TP1	-56124	-3500291
E-TP2	-56226	-3500423
E-TP3	-56273	-3500592
E-TP4	-56250	-3500595
E-TP5	-56255	-3500631
E-TP6	-56278	-3500627
E-TP7	-56404	-3500747
E-TP8	-56619	-3500805
E-TP9	-56791	-3500789
E-TP10	-56714	-3501122
E-TP11	-57012	-3501186
E-TP12	-57186	-3501076
E-TP13	-57407	-3500824
E-TP14	-57180	-3500676
E-TP15	-57041	-3500708
E-TP16	-56858	-3500903
E-TP17	-56997	-3500978
E-TP18	-57137	-3500819
E-TP19	-57565	-3500606
E-TP20	-57848	-3500710
E-TP21	-58165	-3500626
E-TP22	-58323	-3500436
E-TP23	-58497	-3500178
E-TP24	-58568	-3500110
E-TP24_ADD	-58522	-3500123
E-TP25	-58522	-3500074
E-TP26	-58272	-3499927
E-TP27	-58061	-3499708
E-TP28	-57845	-3499497
E-TP29	-57753	-3499278
E-TP30	-57951	-3499043
E-TP31	-58096	-3498788
E-TP32	-58289	-3498541
E-TP33	-58501	-3498335
E-TP34	-58761	-3498149

NOTE:
1) STAKE VALUES SHOWN ONLY APPLY TO THE PATH TAKEN FOR TESTING.

LEGEND

◕	TEST PIT
- - - -	ROUTE
⬭	BAL DAM
🟩	LUTZVILLE CONSERVATIVE AREA

Office: AUDRW Filename: E:\AURECON\MANUALS_ADG\V02\CUSTOMISATION\AUTOCAD\DRGSHTS\ADG_A1HT.DWG Plot Date: ----

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Water and Sanitation
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REV	DATE	REVISION DETAILS	APPROVED
A	09.2020	FOR INFORMATION	

SCALE	SIZE
AS SHOWN	A1

DRAWN
D.BULL

DESIGNED
G.DAVIS

CHECKED
G.DAVIS

INFORMATION
NOT FOR CONSTRUCTION

APPROVED
DATE

PROJECT CLANWILLIAM
BRIDGING STUDY

TITLE EBENHAESER SCHEME
TEST PIT LAYOUT PLAN
SHEET 01 OF 04

DRAWING No.	PROJECT No.	WBS	TYPE	DISC	NUMBER	REV
	113834	0001	DRG	GG	0001	A

TP ID	CO-ORDINATES ON WG84_Lo19	
	Y	X
E-TP34	-58761	-3498149
E-TP35	-59013	-3497974
E-TP36	-59260	-3497803
E-TP37	-59506	-3497628
E-TP38	-59752	-3497454
E-TP39	-60005	-3497306
E-TP40	-60273	-3497169
E-TP41	-60543	-3497045
E-TP42	-60826	-3496963
E-TP43	-61120	-3496872
E-TP44	-61401	-3496753
E-TP45	-61723	-3496692
E-TP46	-61988	-3496622
E-TP47	-62302	-3496593
E-TP48	-62588	-3496479
E-TP49	-62850	-3496314

NOTE:
1) STAKE VALUES SHOWN ONLY APPLY TO THE PATH TAKEN FOR TESTING.

LEGEND

●	TEST PIT
- - - - -	ROUTE
○	BAL DAM
🟩	LUTZVILLE CONSERVATIVE AREA

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Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

REV	DATE	REVISION DETAILS	APPROVED
A	09.2020	FOR INFORMATION	

SCALE: AS SHOWN
SIZE: A1
DRAWN: D.BULL
DESIGNED: G.DAVIS
CHECKED: G.DAVIS

INFORMATION
NOT FOR CONSTRUCTION

APPROVED
DATE

PROJECT: CLANWILLIAM BRIDGING STUDY

TITLE: EBENHAESER SCHEME TEST PIT LAYOUT PLAN SHEET 02 OF 04

DRAWING No.	PROJECT No.	WBS	TYPE	DISC	NUMBER	REV
	113834	0001	DRG	GG	0002	A

TP ID	CO-ORDINATES ON WG84_Lo19	
	Y	X
E-TP49	-62850	-3496314
E-TP50	-63109	-3496151
E-TP51	-63372	-3495982
E-TP52	-63624	-3495823
E-TP53	-63874	-3495654
E-TP54	-64133	-3495478
E-TP55	-64382	-3495314
E-TP56	-64632	-3495151
E-TP57	-64919	-3495108
E-TP58	-65229	-3495089
E-TP59	-65690	-3495115
E-TP60	-65836	-3495035
E-TP61	-66076	-3494899
E-TP62	-66350	-3494809
E-TP63	-66601	-3494618
E-TP64	-66837	-3494371
E-TP65	-67046	-3494221

NOTE:
1) STAKE VALUES SHOWN ONLY APPLY TO THE PATH TAKEN FOR TESTING.

LEGEND

⊗	TEST PIT
-·-·-·-	ROUTE
⬭	BAL DAM
▭	LUTZVILLE CONSERVATIVE AREA

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REV	DATE	REVISION DETAILS	APPROVED
A	09.2020	FOR INFORMATION	

SCALE	SIZE
AS SHOWN	A1

DRAWN
D.BULL

DESIGNED
G.DAVIS

CHECKED
G.DAVIS

INFORMATION
NOT FOR CONSTRUCTION

APPROVED
DATE

PROJECT CLANWILLIAM
BRIDGING STUDY

TITLE EBENHAESER SCHEME
TEST PIT LAYOUT PLAN
SHEET 03 OF 04

DRAWING No.	PROJECT No.	WBS	TYPE	DISC	NUMBER	REV
	113834	0001	DRG	GG	0003	A

TP ID	CO-ORDINATES ON WG84_Lo19	
	Y	X
E-TP64	-66837	-3494371
E-TP65	-67046	-3494221
E-TP66	-67272	-3494001
E-TP67	-67483	-3493799
E-TP68	-67733	-3493672
E-TP69	-68045	-3493652
E-TP70	-68344	-3493589
E-TP71	-68543	-3493553
E-TP72	-68701	-3493776
E-TP73	-68925	-3493651
E-TP74	-69167	-3493862
E-TP75	-69307	-3494029
E-TP76	-69411	-3494269
E-TP77	-69585	-3494570
E-TP78	-69792	-3494858
E-TP79	-69985	-3495017
E-TP80	-70244	-3495135
E-TP81	-70526	-3495248
E-TP82	-70817	-3495341

NOTE:
1) STAKE VALUES SHOWN ONLY APPLY TO THE PATH TAKEN FOR TESTING.

LEGEND

◐	TEST PIT
-------	ROUTE
⬭	BAL DAM
▭	LUTZVILLE CONSERVATIVE AREA

50 0 100 200m
SCALE 1:5000 ON A1

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REV	DATE	REVISION DETAILS	APPROVED
A	09.2020	FOR INFORMATION	

SCALE	SIZE
AS SHOWN	A1

DRAWN
D.BULL

DESIGNED
G.DAVIS

CHECKED
G.DAVIS

INFORMATION
NOT FOR CONSTRUCTION

APPROVED
DATE

PROJECT
CLANWILLIAM
BRIDGING STUDY

TITLE
EBENHAESER SCHEME
TEST PIT LAYOUT PLAN
SHEET 04 OF 04

DRAWING No.	PROJECT No.	WBS	TYPE	DISC	NUMBER	REV
	113834	0001	DRG	GG	0004	A

Appendix B
Summary of Soil and Rock Profile Description Terminology

STANDARD DESCRIPTIONS USED IN SOIL PROFILING

1. MOISTURE CONDITION

Term	Description
Dry	
Slightly moist	Requires addition of water to reach optimum moisture content for compaction
Moist	Near optimum content
Very Moist	Requires drying to attain optimum content
Wet	Fully saturated and generally below water table

2. COLOUR

The Predominant colours or colour combinations are described including secondary coloration described as banded, streaked, blotched, mottled, speckled or stained.

3. CONSISTENCY

3.1 Non-Cohesive Soils

Term	Description
Very Loose	Crumbles very easily when scraped with geological pick
Loose	Small resistance to penetration by sharp end of geological pick
Medium Dense	Considerable resistance to penetration by sharp end of geological pick
Dense	Very high resistance to penetration to sharp end of geological pick. Requires many blows of hand pick for excavation.
Very Dense	High resistance to repeated blows of geological pick. Requires power tools for excavation

3.2 Cohesive Soils

Term	Description
Very soft	Easily penetrated by thumb. Sharp end of pick can be pushed in 30 - 40mm. Easily moulded by fingers.
Soft	Pick head can easily be pushed into the shaft of handle. Moulded by fingers with some pressure.
Firm	Indented by thumb with effort. Sharp end of pick can be pushed in up to 10mm. Can just be penetrated with an ordinary spade.
Stiff	Penetrated by thumbnail. Slight indentation produced by pushing pick point into soil. Cannot be moulded by fingers. Requires hand pick for excavation.
Very Stiff	Indented by thumbnail. Slight indentation produced by blow of pick point. Requires power tools for excavation.

4. STRUCTURE

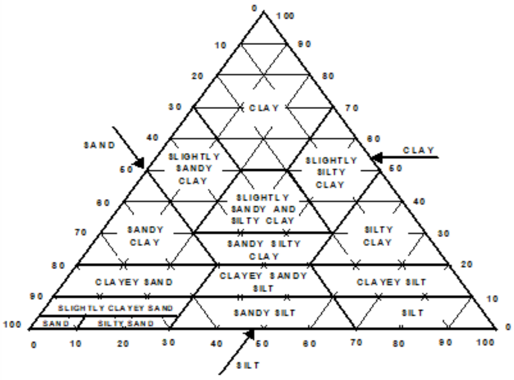
Term	Description
Intact	Absence of fissures or joints
Fissured	Presence of closed joints
Shattered	Presence of closely spaced air-filled joints giving cubical fragments
Micro-shattered	Small scale shattering with shattered fragments the size of sand grains
Slickensided	Polished planar surfaces representing shear movement in soil
Bedded Foliated	Many residual soils show structures of parent rock.

5. SOIL TYPE

5.1 Particle Size

Term	Size (mm)
Boulder	>200
Pebbles	60 – 200
Gravel	60 – 2
Sand	2 – 0,06
Silt	0,06 – 0,002
Clay	<0,002

5.2 Soil Classification



6. ORIGIN

6.1 Transported Soils

Term	Agency of Transportation
Colluvium	Gravity deposits
Talus	Scree or coarse colluvium
Hillwash	Fine colluvium
Alluvial	River deposits
Aeolian	Wind deposits
Litoral	Beach deposits
Estuarine	Tidal – river deposits
Lacustine	Lake deposits

6.2 Residual soils

These are products of in-situ weathering of rocks and are described as e.g. Residual Shale

6.3 Pedocretes

Formed in transported and residual soils etc.
calcrete, silcrete, manganocrete and ferricrete.

SUMMARY OF DESCRIPTIONS USED IN ROCK DESCRIPTION

1. WEATHERING		
Term	Symbol	Diagnostic Features
Residual Soil	W5	Rock is discoloured and completely changed to a soil in which original rock fabric is completely destroyed. There is a large change in volume.
Completely Weathered	W5	Rock is discoloured and changed to a soil, but original fabric is mainly preserved. There may be occasional small corestones.
Highly Weathered	W4	Rock is discoloured, discontinuities may be open and have discoloured surfaces, and the original fabric of the rock near the discontinuities may be altered; alternation penetrates deeply inwards, but corestones are still present.
Moderately Weathered	W3	Rock is discoloured, discontinuities may be open and will have discoloured surfaces with alteration starting to penetrate inwards, intact rock is noticeably weaker than the fresh rock.
Slightly Weathered	W2	Rock may be slightly discoloured, particularly adjacent to discontinuities, which may be open and will have slightly discoloured surfaces, the intact rock is not noticeably weaker than the fresh rock.
Unweathered	W1	Parent rock showing no discolouration, loss of strength or any other weathering effects.

2. HARDNESS		
Classification	Field Test	Compressive Strength Range MPa
Very Soft Rock	Can be peeled with a knife. Material crumbles under firm blows with the sharp end of a geological pick.	1 to 3
Soft Rock	Can be scraped with a knife, indentation of 2 to 4 mm with firm blows of the pick point.	3 to 10
Medium Hard Rock	Cannot be scraped or peeled with a knife. Hand held specimen breaks with firm blows of the pick.	10 to 25
Hard Rock	Point load tests must be carried out in order to distinguish between these classifications	25 - 70
Very Hard Rock	These results may be verified by uniaxial compressive strength tests on selected samples.	70 - 200
Extremely Hard Rock		>200

3. COLOUR
The predominant colours or colour combination are described including secondary colouration described as banded, streaked, blotched, mottled, speckled or stained.

4. FABRIC				
4.1 Grain Size		4.2 Discontinuity Spacing		
Term	Size (mm)	Description for: Bedding, foliation, laminations	Spacing (mm)	Descriptions for joints, faults, etc.
Very Coarse	>2,0	Very Thickly Bedded	> 2000	Very Widely
Coarse	0,6 – 2,0	Thickly Bedded	600 – 2000	Widely
Medium	0,2 – 0,6	Medium Bedded	200 – 600	Medium
Fine	0,06 – 0,2	Thinly Bedded	20 – 200	Closely
Very Fine	< 0,06	Laminated	6 – 20	Very closely
		Thinly Laminated	<6	

5. ROCK NAME	
Classified in terms of origin:	
IGNEOUS	Granite, Diorite, Gabbro, Syenite, Diabase, Dolerite, Trachyte, Andesite, Basalt.
METAMORPHIC	Slate, Quartzite, Gneiss, Schist,
SEDIMENTARY	Shale, Mudstone, Siltstone, Sandstone, Dolomite, Conglomerate, Tillite, Quartzite, Limestone.

6. STRATIGRAPHIC HORIZON
Identification of rock type in terms of stratigraphic horizons.

Appendix C
Test Pit Profiles

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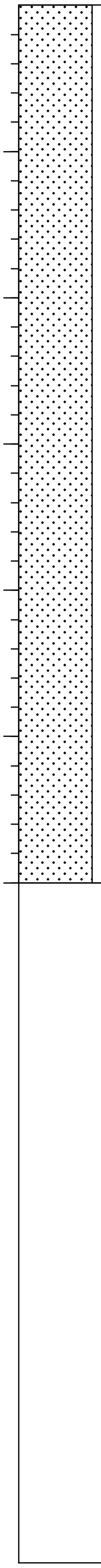
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP01**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00

Slightly moist, orange brown, loose to medium dense, pinholed, silty SAND. Aeolian

3.00

NOTES:

1. No refusal, profiled exposed road cut.
2. No groundwater seepage was encountered.
3. Sidewalls stable.
4. No sample taken.

CONTRACTOR: DWS
MACHINE:
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/28/2020
DATE PROFILED: 7/28/2020

ELEVATION:
X COORD: - 56066
Y COORD: - 3500000

HOLE No: **E-TP01**

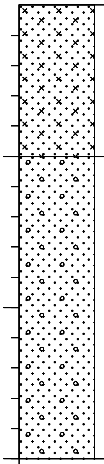
Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP02**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Slightly moist, light brown, loose, pinholed, silty SAND. Aeolian or hillwash
0.50	Slightly moist, light brown blotchd yellow and red, very dense, pinholed, calcretised and ferruginised silty SAND. Pedogenic material
1.50	

<u>NOTES</u>:

1. No refusal, profiled exposed road cut about 85m SW of E-TP02.
2. No groundwater seepage was encountered.
3. Sidewalls stable.
4. No sample taken.

CONTRACTOR: DWS
MACHINE:
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/28/2020
DATE PROFILED: 7/28/2020

ELEVATION:
X COORD: - 56169
Y COORD: - 3500132

HOLE No: **E-TP02**

Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

Scale
1:25

0.00
0.10

Immediately next to river, i.e. on river bank. Not excavated. Assumed same profile as in TP07,i.e. clayey sandy SILT.

NOTES:

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:		*DIAM:*		*X COORD:*	- 56216
PROFILED BY:	K Myburgh and G Davis	*DATE DRILLED:*	7/28/2020	*Y COORD:*	- 3500301
TYPE SET BY:		*DATE PROFILED:*	7/28/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP03**

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Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP04**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25

0.00 0.10	Immediately next to river, i.e. on river bank. Not excavated. Assumed same profile as in TP07,i.e. clayey sandy SILT.

NOTES:

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:		*DIAM:*		*X COORD:*	- 56193
PROFILED BY:	K Myburgh and G Davis	*DATE DRILLED:*	7/28/2020	*Y COORD:*	- 3500305
TYPE SET BY:		*DATE PROFILED:*	7/28/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP04**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

JOB NUMBER: **113834**

Scale
1:25

0.00
0.10

Immediately next to river, i.e. on river bank. Not excavated. Assumed same profile as in TP07.

NOTES:

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:		DIAM:		X COORD:	- 56197
PROFILED BY:	K Myburgh and G Davis	DATE DRILLED:	7/28/2020	Y COORD:	- 3500340
TYPE SET BY:		DATE PROFILED:	7/28/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP05**

HOLE No:	**E-TP06**
	Sheet 1 of 1

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

JOB NUMBER: **113834**

Scale
1:25

0.00
0.10

Immediately next to river, i.e. on river bank. Not excavated. Assumed same profile as in TP07.

NOTES:

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:		DIAM:		X COORD:	- 56220
PROFILED BY:	K Myburgh and G Davis	DATE DRILLED:	7/28/2020	Y COORD:	- 3500336
TYPE SET BY:		DATE PROFILED:	7/28/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP06**

Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

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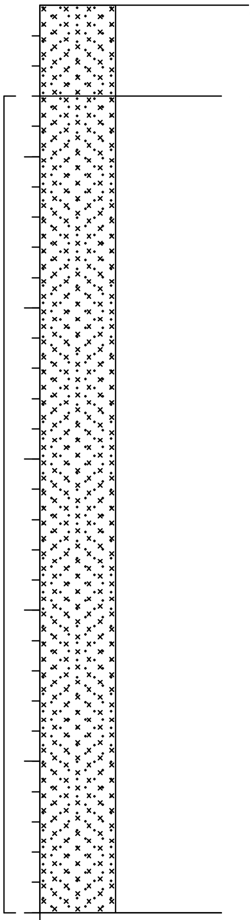
Ebenhaeser Scheme

JOB NUMBER: **113834**

Scale
1:25

sample



0.00	Wet, brown blotched red, soft to firm, intact, clayey sandy SILT. Made ground next to vineyards
0.30	Wet, dark brown, firm, intact, clayey sandy SILT. Alluvium
3.00	

<u>NOTES</u>:

1. No refusal, pit terminated at 3.0m.
2. Seepage encountered at 2.3m, area is on flood plain and was recentely underwater.
3. Sidewalls collapsed.
4. Bulk and small bags sampled between 0.3-3.0m.
5. Test pit moved from original location due to ponding of water.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:		*DIAM:*		*X COORD:*	- 56404
PROFILED BY:	K Myburgh and G Davis	*DATE DRILLED:*	7/28/2020	*Y COORD:*	- 3500747
TYPE SET BY:		*DATE PROFILED:*	7/28/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP07**

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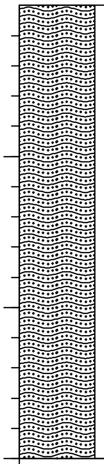
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP08**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	1.50	Grey and yellow green, highly weathered, dipping at 30 degrees, foliated, micaceous soft rock and highly fissile in places. Schist

NOTES:

1. Test pit not excavated, profiled outcrop on slope along the existing canal.
2. No groundwater seepage was encountered.
3. Sidewalls stable.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/28/2020
DATE PROFILED: 7/28/2020

ELEVATION:
X COORD: - 56562
Y COORD: - 3500514

HOLE No: **E-TP08**

Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

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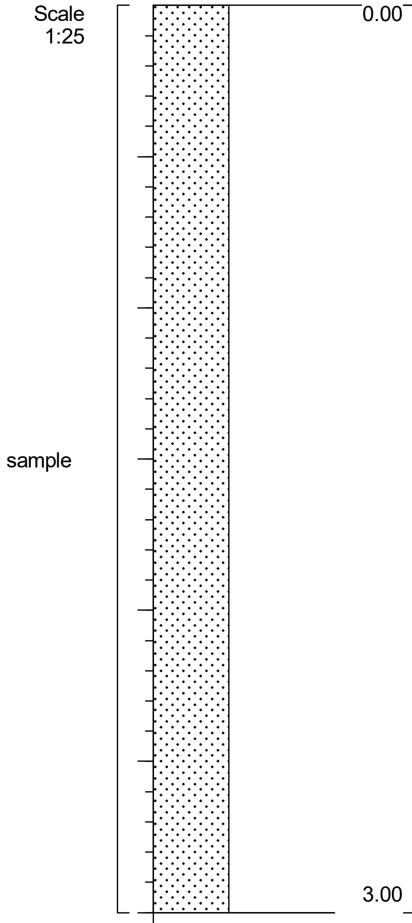
Ebenhaeser Scheme

HOLE No: **E-TP09**
Sheet 1 of 1

JOB NUMBER: **113834**



Slightly moist, orange brown , loose to medium dense, pinholed, SAND. Aeolian

<u>NOTES</u>:

1. No refusal, test pit terminated at end of reach.
2. No groundwater seepage was encountered.
3. Slight sidewall collapse. .
4. Bulk and small bag sample between 0.0-3.0m.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 56719
PROFILED BY:	K Myburgh and G Davis	*DATE DRILLED:*	7/28/2020	*Y COORD:*	- 3500508
TYPE SET BY:		*DATE PROFILED:*	7/28/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP09**

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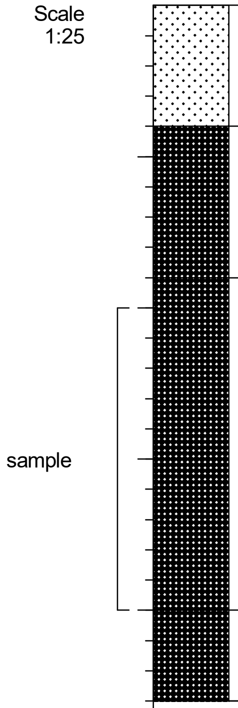
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP10**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Slightly moist, orange brown , loose, pinholed, ferruginised SAND. Pedogenic material
0.40	Slightly moist, yellow and orange brown with white pockets, dense, intact, calcretised and ferruginised SAND with hardpan calcrete gravel sized particles. Pedogenic material from terrace gravels
0.90	Slightly moist, red brown, dense to very dense, honeycomb, nodular fine to medium gravel sized ferruginised SAND. Pedogenic material from terrace gravels
2.00	Slightly moist, orange and red brown, dense, intact, ferruginised and calcritised SAND. Pedogenic material
2.30	

<u>NOTES</u>:

1. Difficults excavation.
2. No groundwater seepage was encountered.
3. Sidewalls stable.
4. Bulk and small bag sampled between 1.0-2.0m.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 56714
PROFILED BY:	K Myburgh and G Davis	*DATE DRILLED:*	7/29/2020	*Y COORD:*	- 3501122
TYPE SET BY:		*DATE PROFILED:*	7/29/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP10**

Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

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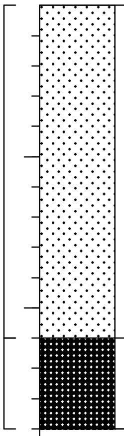
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP11**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



Depth (m)	
0.00	Slightly moist, orange brown, loose to medium dense, pinholed, SAND. Aeolian
1.10	Slightly moist, light brown blotched red and yellow, very dense, pinholed, calcretised and ferruginised SAND. Pedogenic material
1.40	

NOTES:

1. Refusal on very dense ferruginised and calcritised sand.
2. No groundwater seepage was encountered.
3. Sidewalls collapsed.
4. Small bags sampled between 0.0-1.1m and 1.1-1.4m.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 56955
PROFILED BY:	K Myburgh and G Davis	*DATE DRILLED:*	7/29/2020	*Y COORD:*	- 3500895
TYPE SET BY:		*DATE PROFILED:*	7/29/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP11**

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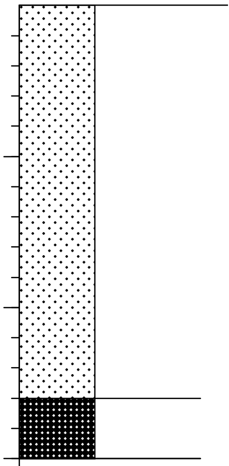
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP12**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Slightly moist, orange brown, loose to medium dense, pinholed,SAND. Aeolian
1.30	Slightly moist, light brown blotched red and yellow, dense to very dense, pinholed, calcretised and ferruginised SAND. Pedogenic material
1.50	

NOTES:

1. Refusal on hard rock schist at the base of the test pit.
2. No groundwater seepage was encountered.
3. Sidewalls stable.
4. No sample taken.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 57186
PROFILED BY:	K Myburgh and G Davis	*DATE DRILLED:*	7/29/2020	*Y COORD:*	- 3501076
TYPE SET BY:		*DATE PROFILED:*	7/29/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP12**

Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

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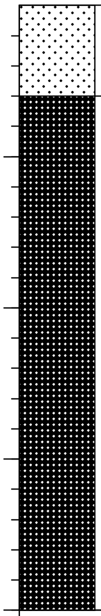
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP13**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Slightly moist, red brown, loose, pinholed, SAND. Aeolian
0.30	Slightly moist, light brown blotched red and yellow, dense to very dense, pinholed, calcretised and ferruginised SAND. Pedogenic material
2.00	

NOTES:

1. Refusal on very dense ferruginised and calcritised sand.
2. No groundwater seepage was encountered.
3. Sidewalls stable.
4. No sample taken.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 57350
PROFILED BY:	K Myburgh and G Davis	*DATE DRILLED:*	7/29/2020	*Y COORD:*	- 3500533
TYPE SET BY:		*DATE PROFILED:*	7/29/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP13**

Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

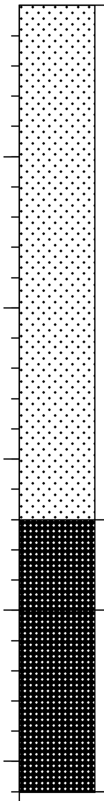
Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP14**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25

sample



0.00	Slightly moist, red brown, loose to medium dense, pinholed, SAND. Aeolian
1.70	Dry, white, medium dense, pinholed, nodular CALCRETE. Pedogenic material
2.00	Slightly moist, red brown, medium dense to dense, pinholed, calcretised and ferruginised SAND. Pedogenic material
2.60	

NOTES:

1. Refusal on very dense ferruginised and calcritised sand.
2. No groundwater seepage was encountered.
3. Sidewalls collapsed.
4. Bulk and small bags sampled between 0.0-1.7m.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/29/2020
DATE PROFILED: 7/29/2020

ELEVATION:
X COORD: - 57180
Y COORD: - 3500676

HOLE No: **E-TP14**

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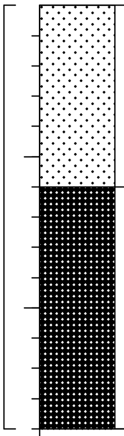
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP15**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25

sample



0.00	Slightly moist, orange brown, loose to medium dense, pinholed, SAND. Aeolian
0.60	Slightly moist, light brown blotched red and yellow, dense to very dense, pinholed, calcretised and ferruginised SAND. Pedogenic material
1.40	

<u>NOTES</u>:

1. Refusal on very dense ferruginised and calcritised sand.
2. No groundwater seepage was encountered.
3. Sidewalls collapsed.
4. Bulk and small bags sampled between 0.0-1.4m.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 56984
PROFILED BY:	K Myburgh and G Davis	*DATE DRILLED:*	7/29/2020	*Y COORD:*	- 3500417
TYPE SET BY:		*DATE PROFILED:*	7/29/2020		

EBENHAESER SCHEME.GPJ

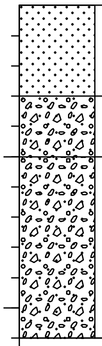
HOLE No: **E-TP15**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP16**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



sample

0.00	Slightly moist, orange brown , loose, pinholed, SAND. Aeolian /Topsoil
0.30	Tightly packed, sub angular to sub rounded, fine to course GRAVEL with a matrix of slightly moist, light brown silty sand. Overall consistency is loose. Terrace gravel
0.50	Tightly packed, sub angular to sub rounded, fine to course GRAVEL with a matrix of calcretised and ferruginised, slightly moist, light brown, silty sand. Overall consistency is very dense. Terrace gravel
1.10	

<u>NOTES</u>:

1. Refusal on terrace gravel, difficult excavation.
2. No groundwater seepage was encountered.
3. Sidewalls stable.
4. Small bag sampled between 0.3-0.5m.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/29/2020
DATE PROFILED: 7/29/2020

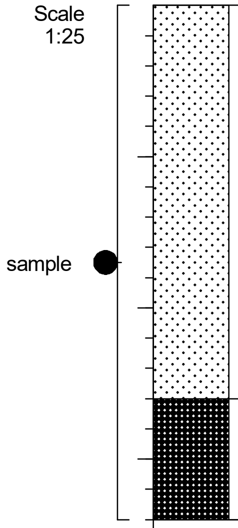
ELEVATION:
X COORD: - 56800
Y COORD: - 3500612

HOLE No: **E-TP16**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP17**
Sheet 1 of 1

JOB NUMBER: **113834**



0.00	Slightly moist, orange brown, loose to medium dense, pinholed, SAND. Aeolian
1.30	Slightly moist, light brown blotched red and yellow, very dense, pinholed, calcretised and ferruginised SAND. Pedogenic material
1.70	

<u>NOTES</u>:

1. Refusal on very dense ferruginised and calcritised sand.
2. No groundwater seepage was encountered.
3. Sidewalls collapsed.
4. Small bags sampled between 0.0-1.7m.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:

EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/29/2020
DATE PROFILED: 7/29/2020

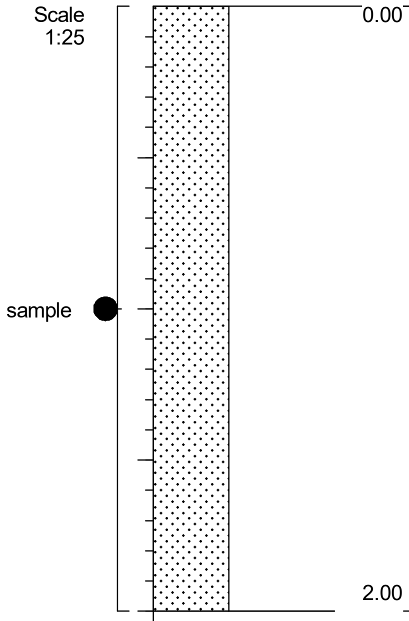
ELEVATION:
X COORD: - 56939
Y COORD: - 3500687

HOLE No: **E-TP17**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP18**
Sheet 1 of 1

JOB NUMBER: **113834**



Slightly moist, orange brown, loose to medium dense, pinholed, SAND. Aeolian

NOTES:

1. No refusal, test pit terminated due to continual sidewall collapse.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. Two small bags sample between 0.0-2.0m.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 57137
PROFILED BY:	K Myburgh and G Davis	*DATE DRILLED:*	7/29/2020	*Y COORD:*	- 3500819
TYPE SET BY:		*DATE PROFILED:*	7/29/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP18**

HOLE No: **E-TP19**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25

0.00
0.10

Test pit not excavated due to accessibility constrains.

NOTES:

Not excavated due to access

CONTRACTOR:
MACHINE:
PROFILED BY:
TYPE SET BY:
INCLINATION:
DIAM:
DATE DRILLED: 7/29/2020
DATE PROFILED:
ELEVATION:
X COORD: - 57508
Y COORD: - 3500316

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP19**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP20**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25

0.00
0.10

Test pit not excavated due to accessibility constrains.

NOTES:

Not excavated due to access

CONTRACTOR:		INCLINATION:		ELEVATION:	
MACHINE:		DIAM:		X COORD:	- 57791
PROFILED BY:		DATE DRILLED:	7/29/2020	Y COORD:	- 3500420
TYPE SET BY:		DATE PROFILED:			

EBENHAESER SCHEME.GPJ

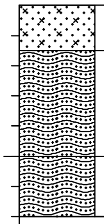
HOLE No: **E-TP20**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP21**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00 0.15	Slightly moist, light brown , loose, intact, silty SAND. Colluvium
0.50	Grey and yellow green, highly weathered, sub-horizontally dipping, foliated, micaceous very soft to soft rock and highly fissile. Schist
0.70	Grey and yellow green, highly to moderately weathered, sub-horizontally dipping, foliated, micaceous soft to medium hard rock. Schist

NOTES:

1. Refusal on soft to medium hard schist.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/28/2020
DATE PROFILED: 7/28/2020

ELEVATION:
X COORD: - 58165
Y COORD: - 3500626

HOLE No: **E-TP21**

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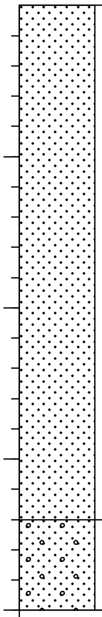
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP22**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Slightly moist, red brown, loose to medium dense, pinholed, SAND. Aeolian
1.70	Slightly moist, red brown blotched yellow, medium dense, pinholed, calcretised and ferrugunisd SAND. Pedogenic material
2.00	

<u>NOTES</u>:

1. Refusal on assumed hardpan calcrete, but hole collapsed.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/27/2020
DATE PROFILED: 7/27/2020

ELEVATION:
X COORD: - 58266
Y COORD: - 3500145

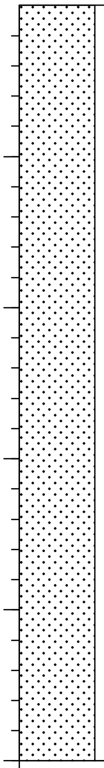
HOLE No: **E-TP22**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP23**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00

Slightly moist, orange brown, loose to medium dense, pinholed, SAND. Aeolian

2.50

NOTES:

1. No refusal, terminated due to continual sidewall collapse.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. No sample taken.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 58440
PROFILED BY:	K Myburgh and G Davis	*DATE DRILLED:*	7/27/2020	*Y COORD:*	- 3499887
TYPE SET BY:		*DATE PROFILED:*	7/27/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP23**

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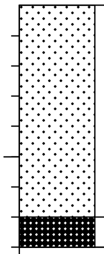
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP24**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Slightly moist, orange brown, loose to medium dense, pinholed, SAND. Aeolian
0.70 0.80	Slightly moist, brown, dense, intact, calcretised and ferruginised sand, gravels are calcretised and ferruginised SAND and quartzite. Pedogenic material

<u>NOTES</u>:

1. Refusal on very dense ferruginised and calcritised gravel layer.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. No sample taken.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	Bell 315SK TLB	DIAM:		X COORD:	- 58511
PROFILED BY:	K Myburgh and G Davis	DATE DRILLED:	7/27/2020	Y COORD:	- 3499819
TYPE SET BY:		DATE PROFILED:	7/27/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP24**

Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

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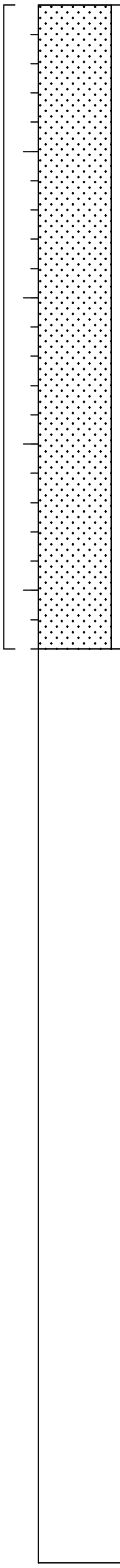
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP24 ADD**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25

sample



Depth	Description
0.00 – 2.20	Slightly moist, orange brown, loose to medium dense, pinholed, SAND. Aeolian

NOTES:

1. No refusal, terminated due to continual sidewall collapse.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. Bulk and small bags sample between 0.0-2.2m.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/27/2020
DATE PROFILED: 7/27/2020

ELEVATION:
X COORD: - 58522
Y COORD: - 3500123

HOLE No: **E-TP24 ADD**

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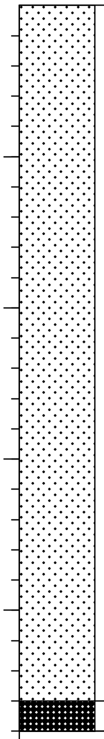
Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP25**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Slightly moist, orange brown, loose to medium dense, pinholed, SAND. Aeolian
2.30	Dry, white, very dense, intact, HARDPAN CALCRETE, Pedogenic material
2.40	

<u>NOTES</u>:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. No sample taken.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 58465
PROFILED BY:	K Myburgh and G Davis	*DATE DRILLED:*	7/27/2020	*Y COORD:*	- 3499783
TYPE SET BY:		*DATE PROFILED:*	7/27/2020		

EBENHAESER SCHEME.GPJ

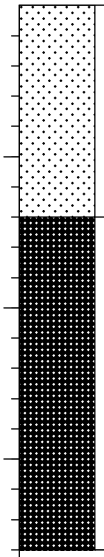
HOLE No: **E-TP25**

HOLE No: **E-TP26**
Sheet 1 of 1

JOB NUMBER: **113834**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

Scale
1:25



0.00	Slightly moist, orange brown, loose to medium dense, pinholed, SAND. Aeolian
0.70	Slightly moist, light brown blotched red and yellow, dense, intact, calcretised and ferruginised SAND. Pedogenic
1.80	

NOTES:

1. Refusal on very dense ferruginised and calcritised gravel layer.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. No sample taken.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 58215
PROFILED BY:	K Myburgh and G Davis	*DATE DRILLED:*	7/27/2020	*Y COORD:*	- 3499636
TYPE SET BY:		*DATE PROFILED:*	7/27/2020		

EBENHAESER SCHEME.GPJ

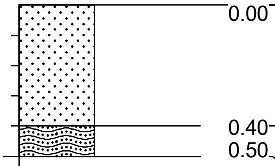
HOLE No: **E-TP26**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP27**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



Slightly moist, orange brown , loose to medium dense, pinholed, SAND. Aeolian

Grey and brown, slightly weathered, medium hard rock,sub horizontally dipping foliated, Schist.

<u>NOTES</u>:

1. Refusal on medium hard rock schist.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/27/2020
DATE PROFILED: 7/27/2020

ELEVATION:
X COORD: - 58004
Y COORD: - 3499417

HOLE No: **E-TP27**

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Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP28**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25

sample

0.00	Slightly moist, orange brown , loose to medium dense, pinholed, SAND. Aeolian
2.50	

NOTES:

1. Refusal on hardpan calcritised and ferruginised sand. .
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. Bulk sample between 0.0-2.5m.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 57775
PROFILED BY:	K Myburgh and G Davis	*DATE DRILLED:*	7/27/2020	*Y COORD:*	- 3499208
TYPE SET BY:		*DATE PROFILED:*	7/27/2020		

EBENHAESER SCHEME.GPJ

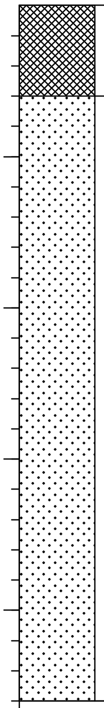
HOLE No: **E-TP28**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP29**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Dry, brown, loose, intact, SAND. Made ground
0.30	Dry, red brown, loose to medium dense, pinholed, SAND. Aeolian
2.30	

NOTES:

1. No refusal, terminated due to continual sidewall collapse.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. No sample taken.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	Bell 315SK TLB	DIAM:		X COORD:	- 57753
PROFILED BY:	K Myburgh and G Davis	DATE DRILLED:	7/24/2020	Y COORD:	- 3499278
TYPE SET BY:		DATE PROFILED:	7/24/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP29**

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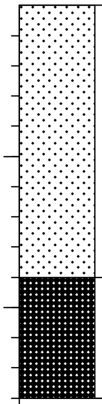
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP30**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Slightly moist, red brown, loose to medium dense, pinholed, SAND. Aeolian
0.90	Slightly moist, red brown blotched yellow, dense to very dense, intact, calcretised and ferrugunisd SAND. Pedogenic material
1.30	

NOTES:

1. Refusal on very dense calcretised and ferruginised sand, intersection between aeolian and pedogenic.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. No sample taken.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 57951
PROFILED BY:	K Myburgh and G Davis	*DATE DRILLED:*	7/24/2020	*Y COORD:*	- 3499043
TYPE SET BY:		*DATE PROFILED:*	7/24/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP30**

Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

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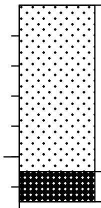
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP31**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



Depth	Description
0.00	Slightly moist, red brown, loose to medium dense, pinholed, SAND. Aeolian
0.55 0.65	Slightly moist, red brown blotched yellow, dense to very dense, intact, calcretised and ferrugunisd SAND. Pedogenic material

<u>NOTES</u>:

1. Refusal on very dense calcretised and ferruginised sand.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. No sample taken. .

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 58096
PROFILED BY:	K Myburgh and G Davis	*DATE DRILLED:*	7/24/2020	*Y COORD:*	- 3498788
TYPE SET BY:		*DATE PROFILED:*	7/24/2020		

EBENHAESER SCHEME.GPJ

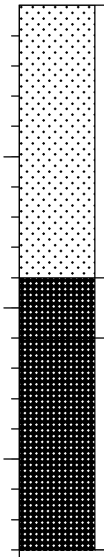
HOLE No: **E-TP31**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP32**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Slightly moist, red brown, loose to medium dense, pinholed, SAND. Aeolian
0.90	Slightly moist, red brown blotched yellow, dense to very dense, pinholed, calcretised and ferrugunisd SAND. Pedogenic material
1.10	Dry, white, dense to very dense, intact, hardpan CALCRETE. Pedogenic material
1.80	

NOTES:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. No sample taken. .

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/24/2020
DATE PROFILED: 7/24/2020

ELEVATION:
X COORD: - 58224
Y COORD: - 3498240

HOLE No: **E-TP32**

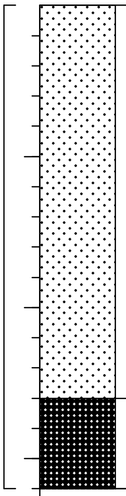
Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP33**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25

sample



0.00	Slightly moist, red brown, loose to medium dense, pinholed, SAND. Aeolian
1.30	Slightly moist, red brown blotched yellow, dense to very dense, pinholed, calcretised and ferrugunisd SAND. Pedogenic material
1.60	

<u>NOTES</u>:

1. Refusal on very dense calcretised and ferruginised sand.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. Bulk sampled between 0.0-1.6m.
5. Small bag taken between 1.3-1.6m.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/24/2020
DATE PROFILED: 7/24/2020

ELEVATION:
X COORD: - 58436
Y COORD: - 3498034

HOLE No: **E-TP33**

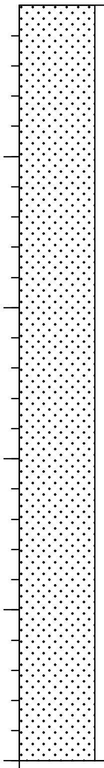
Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP34**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00

Slightly moist, orange brown, loose to medium dense, pinholed, SAND. Aeolian

2.50

NOTES:

1. No refusal, terminated due to continual sidewall collapse.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:

INCLINATION:
DIAM:
DATE DRILLED: 7/24/2020
DATE PROFILED: 7/24/2020

ELEVATION:
X COORD: - 58696
Y COORD: - 3497847

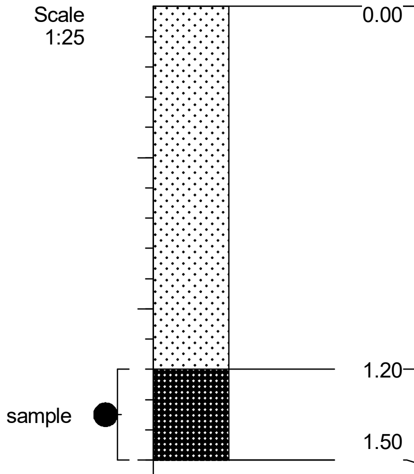
HOLE No: **E-TP34**

EBENHAESER SCHEME.GPJ

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP35**
Sheet 1 of 1

JOB NUMBER: **113834**



Slightly moist, orange brown, loose to medium dense, pinholed, SAND. Aeolian

Slightly moist, orange brown, dense to very dense, pinholed, calcretised and ferrugunisd SAND. Pedogenic material

NOTES:

1. Refusal on very dense calcretised and ferruginised sand.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. Small bag sampled between 1.2-1.5m.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/24/2020
DATE PROFILED: 7/24/2020

ELEVATION:
X COORD: - 58954
Y COORD: - 3497674

HOLE No: **E-TP35**

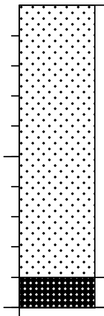
Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

HOLE No: **E-TP36**
Sheet 1 of 1

JOB NUMBER: **113834**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

Scale
1:25



Depth	Description
0.00	Slightly moist, red brown, loose to medium dense, pinholed, SAND. Aeolian
0.90 1.00	Slightly moist, brown blotched red and white, very dense, honeycomb, hardpan calcretised and ferrugunisd SAND and hardpan NODULES. Pedogenic material

NOTES:

1. Refusal on hardpan calcretised and ferruginised sand.
2. No groundwater seepage was encountered.
3. Sidewalls collapsed.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/24/2020
DATE PROFILED: 7/24/2020

ELEVATION:
X COORD: - 59196
Y COORD: - 3497506

HOLE No: **E-TP36**

Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

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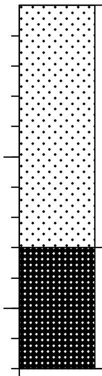
Department of Water and Sanitation

Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP37**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Slightly moist, red brown, loose to medium dense, pinholed, SAND. Aeolian
0.80	Slightly moist, brown blotched red and white, very dense, honeycomb, HARDPAN calcretised and ferrugunisd SAND. Pedogenic material
1.20	

<u>NOTES</u>:

1. Refusal on hardpan calcrete, intersection between aeolian and pedogenic.
2. No groundwater seepage was encountered.
3. Sidewalls collapsed.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/24/2020
DATE PROFILED: 7/24/2020

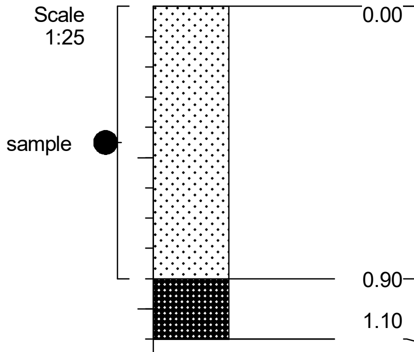
ELEVATION:
X COORD: - 59449
Y COORD: - 3497337

HOLE No: **E-TP37**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP38**
Sheet 1 of 1

JOB NUMBER: **113834**



Depth	Description
0.00	Slightly moist, red brown, loose to medium dense, pinholed, SAND. Aeolian
0.90–1.10	Dry, white, very dense, intact, hardpan CALCRETE. Pedogenic material

<u>NOTES</u>:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. Bulk and small bags sample between 0.0-0.9m.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/24/2020
DATE PROFILED: 7/24/2020

ELEVATION:
X COORD: - 59694
Y COORD: - 3497163

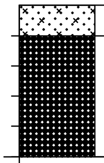
HOLE No: **E-TP38**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP39**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00
0.10 Slightly moist, orange brown , loose, intact, silty SAND. Topsoil

0.50 Slightly moist, brown blotched red and white, very dense, honeycomb, HARDPAN calcretised and ferrugunisd SAND. Pedogenic material

NOTES:

1. Refusal on hardpan calcritised and ferruginised sand. Very difficult excavation
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/24/2020
DATE PROFILED: 7/24/2020

ELEVATION:
X COORD: - 59948
Y COORD: - 3497015

HOLE No: **E-TP39**

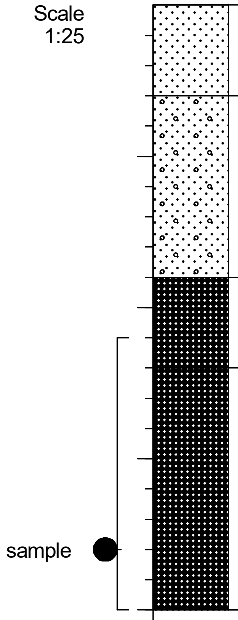
HOLE No: E-TP40

Sheet 1 of 1

JOB NUMBER: 113834

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

Scale
1:25



0.00	Slightly moist, yellow brown, loose, pinholed, SAND. Aeolian
0.30	Dry, light brown , medium dense, intact, silty SAND with calcrete NODULES. Pedogenic material
0.90	Slightly moist, orange brown, dense, honeycomb, calcretised SAND. Pedogenic material
1.20	Slightly moist, brown blotched red, dense, intact, ferruginised SAND with ferricrete nodules. Pedogenic material
2.00	

NOTES:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. Small bag sampled between 1.1-2.5m.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 60210
PROFILED BY:	K Myburgh and G Davis	*DATE DRILLED:*	7/23/2020	*Y COORD:*	- 3496865
TYPE SET BY:		*DATE PROFILED:*	7/23/2020		
	EBENHAESER SCHEME.GPJ				

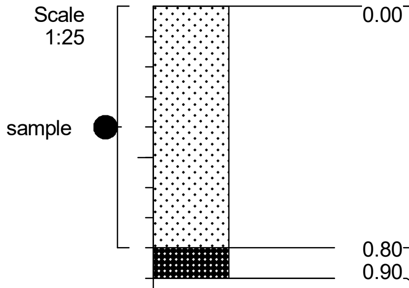
HOLE No: E-TP40

HOLE No: **E-TP41**

Sheet 1 of 1

JOB NUMBER: **113834**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme



Depth	Description
0.00 – 0.80	Slightly moist, orange brown, loose to medium dense, pinholed, SAND. Aeolian
0.80 – 0.90	Dry, white, very dense, intact, HARDPAN calcrete. Pedogenic material

NOTES:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. Small bag sampled between 0.0-0.8m.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: K Myburgh and G Davis
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/23/2020
DATE PROFILED: 7/23/2020

ELEVATION:
X COORD: - 60485
Y COORD: - 3496754

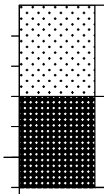
HOLE No: **E-TP41**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP42**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Slightly moist, brown , medium dense, intact, silty SAND. Colluvium
0.30	Dry, white, very dense, intact, HARDPAN calcrete. Pedogenic material
0.60	

NOTES:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	Bell 315SK TLB	DIAM:		X COORD:	- 60769
PROFILED BY:	K Myburgh and G Davis	DATE DRILLED:	7/23/2020	Y COORD:	- 3496672
TYPE SET BY:		DATE PROFILED:	7/23/2020		

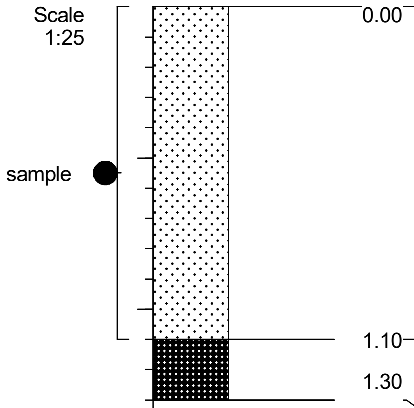
EBENHAESER SCHEME.GPJ

HOLE No: **E-TP42**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP43**
Sheet 1 of 1

JOB NUMBER: **113834**



Slightly moist to moist, brown , very loose, intact, SAND. Aeolian

Brown and black, clast supported highly cemented calcritised angular gravel, very dense to very soft rock. Hardpan calcrete

<u>NOTES</u>:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. Small bag sampled between 0.0-1.1m.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/24/2020
DATE PROFILED: 7/24/2020

ELEVATION:
X COORD: - 61120
Y COORD: - 3496872

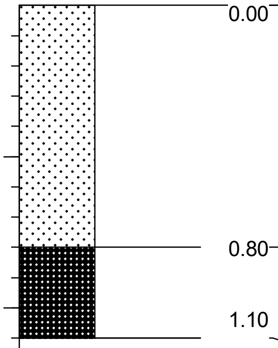
HOLE No: **E-TP43**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP44**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00 Slightly moist to moist, brown , very loose to lose, intact, SAND. Aeolian

0.80 Brown and black, clast supported highly cemented calcritised angular gravel, very dense to very soft rock. Hardpan calcrete

1.10

NOTES:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. No sample taken.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 61401
PROFILED BY:	S. Nyathi and M Sikwe	*DATE DRILLED:*	7/24/2020	*Y COORD:*	- 3496753
TYPE SET BY:		*DATE PROFILED:*	7/24/2020		

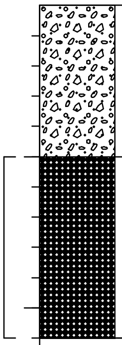
EBENHAESER SCHEME.GPJ

HOLE No: **E-TP44**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

JOB NUMBER: **113834**

Scale
1:25



0.00	Slightly moist to moist, brown speckled off-white , loose to medium dense, intact, silty SAND with fine to medium GRAVEL. Colluvium
0.50	Off-white and brown, matrix supported, angular, highly cemented, very dense CALCRETE nodules and honeycombed in a matrix of slightly moist silty sand. Pedogenic material from terrace gravels
1.10	

NOTES:

1. Refusal on very soft rock schist.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. Bulk sampled between 0.5-1.1m.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	Bell 315SK TLB	DIAM:		X COORD:	- 61723
PROFILED BY:	S. Nyathi and M Sikwe	DATE DRILLED:	7/24/2020	Y COORD:	- 3496692
TYPE SET BY:		DATE PROFILED:	7/24/2020		

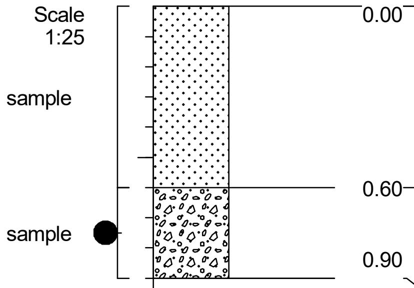
EBENHAESER SCHEME.GPJ

HOLE No: **E-TP45**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP46**
Sheet 1 of 1

JOB NUMBER: **113834**



Slightly moist to moist, reddish brown , loose to medium dense, intact, SAND. Aeolian

Brown, grey and off-white, matrix supported, angular to sub-angular fine to medium GRAVEL in a matrix of slightly moist silty sand. overall consistency is medium dense to dense. Terrace gravel

<u>NOTES</u>:

1. Refusal on very soft rock schist.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. Bulk sampled between 0.0-0.6m.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 61988
PROFILED BY:	S. Nyathi and M Sikwe	*DATE DRILLED:*	7/24/2020	*Y COORD:*	- 3496622
TYPE SET BY:		*DATE PROFILED:*	7/24/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP46**

Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

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Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP47**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25

▨	0.00 0.50	Brown, off-white and red, highly weathered, fine grained, laminated, very soft rock with quartz veins. Schist

<u>NOTES</u>:

1. Logged cut face, outcrops in the area. .
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 62302
PROFILED BY:	S. Nyathi and M Sikwe	*DATE DRILLED:*	7/24/2020	*Y COORD:*	- 3496593
TYPE SET BY:		*DATE PROFILED:*	7/24/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP47**

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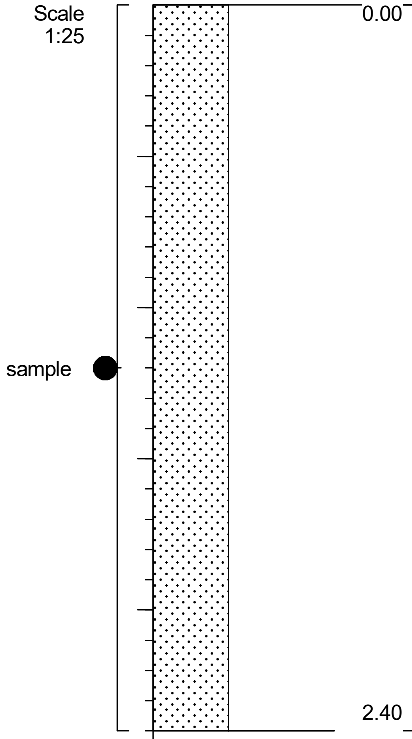
Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP48**
Sheet 1 of 1

JOB NUMBER: **113834**



Slightly moist to moist, reddish brown , very loose to loose, pinholed, SAND. Aeolian (sand dunes)

NOTES:

1. No refusal, test pit unsafe.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. Small bag between 0.0-2.4m.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 62588
PROFILED BY:	S. Nyathi and M Sikwe	*DATE DRILLED:*	7/24/2020	*Y COORD:*	- 3496479
TYPE SET BY:		*DATE PROFILED:*	7/24/2020		

EBENHAESER SCHEME.GPJ

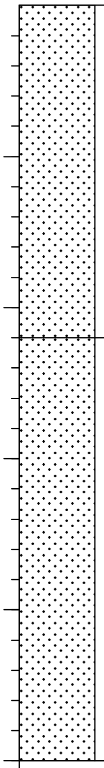
HOLE No: **E-TP48**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP49**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00 Slightly moist to moist, reddish brown , very loose to loose, pinholed, SAND. Aeolian (sand dunes)

1.10 Moist, reddish brown , medium dense, pinholed, SAND. Aeolian (sand dunes)

2.50

<u>NOTES</u>:

1. No refusal, test pit unsafe.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/24/2020
DATE PROFILED: 7/24/2020

ELEVATION:
X COORD: - 62850
Y COORD: - 3496314

HOLE No: **E-TP49**

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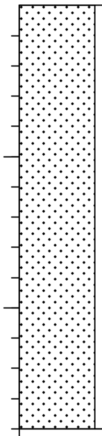
Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP50**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00

Slightly moist to moist, reddish brown , loose to medium dense, intact, SAND. Aeolian (sand dunes)

1.40

NOTES:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/24/2020
DATE PROFILED: 7/24/2020

ELEVATION:
X COORD: - 63109
Y COORD: - 3496151

HOLE No: **E-TP50**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

Scale
1:25

Depth	Description
0.00	Slightly moist to moist, reddish brown, loose, pinholed, SAND. Aeolian (sand dunes)
1.00	

NOTES:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. No sample taken.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	Bell 315SK TLB	DIAM:		X COORD:	- 63372
PROFILED BY:	S. Nyathi and M Sikwe	DATE DRILLED:	7/24/2020	Y COORD:	- 3495982
TYPE SET BY:		DATE PROFILED:	7/24/2020		

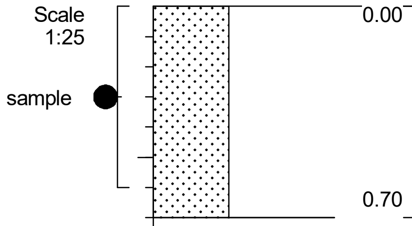
EBENHAESER SCHEME.GPJ

HOLE No: **E-TP51**

aurecon **Department of Water and Sanitation**
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP52**
Sheet 1 of 1

JOB NUMBER: **113834**



Slightly moist to moist, reddish brown, loose, intact, SAND. Aeolian (sand dunes)

NOTES:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. Small bag between 0.0-0.6m.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 63624
PROFILED BY:	S. Nyathi and M Sikwe	*DATE DRILLED:*	7/24/2020	*Y COORD:*	- 3495823
TYPE SET BY:		*DATE PROFILED:*	7/24/2020		
	EBENHAESER SCHEME.GPJ				

HOLE No: **E-TP52**

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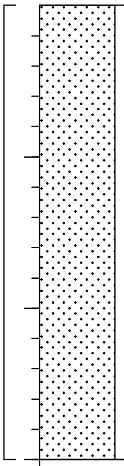
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP53**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00

Slightly moist to moist, reddish brown, loose to medium dense, pinholed, SAND. Aeolian (sand dunes)

1.50

NOTES:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. Bulk sampled between 0.0-1.5m.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:

INCLINATION:
DIAM:
DATE DRILLED: 7/24/2020
DATE PROFILED: 7/24/2020

ELEVATION:
X COORD: - 63874
Y COORD: - 3495654

EBENHAESER SCHEME.GPJ

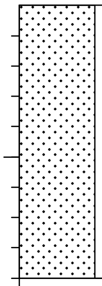
HOLE No: **E-TP53**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP54**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



Depth	Description
0.00	Slightly moist to moist, reddish brown, loose, intact, SAND. Aeolian (sand dunes)
0.90	

NOTES:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 64133
PROFILED BY:	S. Nyathi and M Sikwe	*DATE DRILLED:*	7/24/2020	*Y COORD:*	- 3495478
TYPE SET BY:		*DATE PROFILED:*	7/24/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP54**

aurecon **Department of Water and Sanitation**
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP55**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25

0.00 – 0.70	Moist, reddish brown, very loose, pinholed, SAND. Aeolian (sand dunes)

NOTES:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall collapsed.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/27/2020
DATE PROFILED: 7/27/2020

ELEVATION:
X COORD: - 64382
Y COORD: - 3495314

HOLE No: **E-TP55**

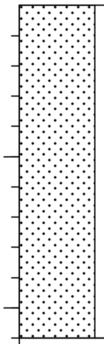
Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP56**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



Depth	Description
0.00	Moist, reddish brown, loose, intact, SAND. Aeolian (sand dunes)
1.10	

NOTES:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:

INCLINATION:
DIAM:
DATE DRILLED: 7/27/2020
DATE PROFILED: 7/27/2020

ELEVATION:
X COORD: - 64632
Y COORD: - 3495151

EBENHAESER SCHEME.GPJ

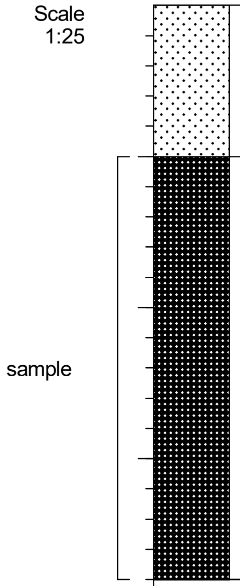
HOLE No: **E-TP56**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP57**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Moist, reddish brown, loose to medium dense, intact, SAND. Aeolian (sand dunes)
0.50	Slightly moist, off-white and brown, dense to very dense, intact, calcritised silty sand with fine to medium calcrete nodules and honeycombed gravel. Pedogenic material
1.90	

<u>NOTES</u>:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. Bulk sampled between 0.5-1.9m.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/27/2020
DATE PROFILED: 7/27/2020

ELEVATION:
X COORD: - 64919
Y COORD: - 3495108

HOLE No: **E-TP57**

Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP58**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25

0.00 0.20	▩	Brown and off-white, highly cemented, very soft rock. Hardpan calcrete

NOTES:

1. Refusal on hardpan calcrete, immediate surroundings are hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/27/2020
DATE PROFILED: 7/27/2020

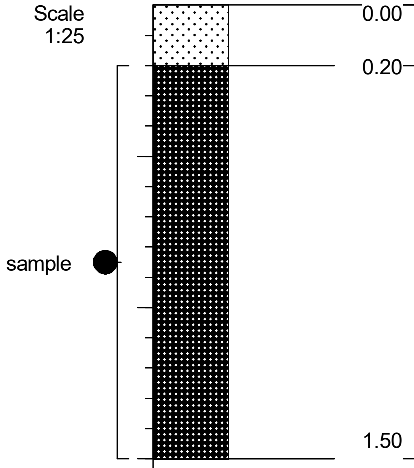
ELEVATION:
X COORD: - 65229
Y COORD: - 3495089

HOLE No: **E-TP58**

aurecon **Department of Water and Sanitation**
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP59**
Sheet 1 of 1

JOB NUMBER: **113834**



0.00	Moist, brown, loose, intact, gravelly SAND. Aeolian
0.20	Slightly moist, off-white and brown, dense to very dense, intact, calcritised silty sand with fine to medium calcrete nodules and honeycombed gravel. Pedogenic material
1.50	

<u>NOTES</u>:

1. Refusal on hardpan calcrete, immediate surroundings are hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. Small bag between 0.2-1.5m.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/27/2020
DATE PROFILED: 7/27/2020

ELEVATION:
X COORD: - 65690
Y COORD: - 3495115

HOLE No: **E-TP59**

Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP60**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25

▒	0.00 0.40	Slightly moist, off-white and brown, intact, calcritised and ferruginised silty sand with fine to medium calcrete nodules and honeycombed gravel. Pedogenic material

<u>NOTES</u>:

1. Refusal on hardpan calcrete, immediate surroundings are hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	Bell 315SK TLB	DIAM:		X COORD:	- 65836
PROFILED BY:	S. Nyathi and M Sikwe	DATE DRILLED:	7/27/2020	Y COORD:	- 3495035
TYPE SET BY:		DATE PROFILED:	7/27/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP60**

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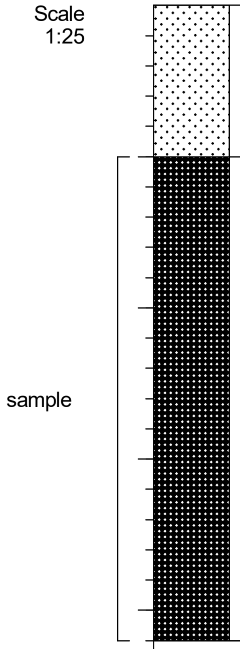
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP61**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Moist, brown, loose, pinholed, SAND. Aeolian
0.50	Off-white and brown, moderately cemented calcrete gravel (nodules) in a matrix of slightly moist silty sand. Overall consistency is medium dense to dense. Pedogenic material
2.10	

<u>NOTES</u>:

1. Refusal on hardpan calcrete, immediate surroundings are hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. Bulk sample between 0.5-2.1m.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/27/2020
DATE PROFILED: 7/27/2020

ELEVATION:
X COORD: - 66076
Y COORD: - 3494899

HOLE No: **E-TP61**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP62**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25

0.00 0.10	Brown, off-white and red, highly weathered, fine grained, laminated, very soft rock with quartz veins. Schist

NOTES:

1. Outcrop in the area, hard excavation expected.
2. No sample taken.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 66350
PROFILED BY:	S. Nyathi and M Sikwe	*DATE DRILLED:*	7/27/2020	*Y COORD:*	- 3494809
TYPE SET BY:		*DATE PROFILED:*	7/27/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP62**

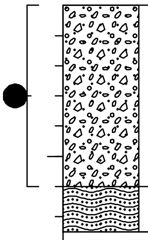
Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP63**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25

sample



0.00	Brown, red, grey and off-white, matrix supported, angular to sub-angular fine to medium, ferruginised and calcritised GRAVEL in a matrix of slightly moist silty sand. overall consistency is medium dense to dense. Terrace gravel
0.60	Brown, off-white and red, highly weathered, fine grained, laminated, very soft rock with quartz veins. Schist
0.75	

<u>NOTES</u>:

1. Refusal on very soft rock schist. .
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. Small bag between 0.0-0.6m.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:

INCLINATION:
DIAM:
DATE DRILLED: 7/27/2020
DATE PROFILED: 7/27/2020

ELEVATION:
X COORD: - 66601
Y COORD: - 3494618

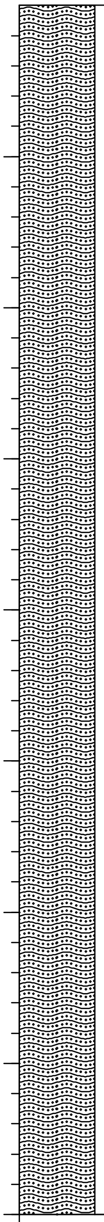
EBENHAESER SCHEME.GPJ

HOLE No: **E-TP63**

HOLE No: **E-TP64**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00

Dark grey, off white and brown, highly to moderately weathering, laminated, fined grained, very soft to soft rock with abundant quartz vained. Micaceous schist

4.00

NOTES:

1. Logged a cut face of redundant road.
2. No seepage.
3. No sample taken.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 66837
PROFILED BY:	S. Nyathi and M Sikwe	*DATE DRILLED:*	7/29/2020	*Y COORD:*	- 3494371
TYPE SET BY:		*DATE PROFILED:*	7/29/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP64**

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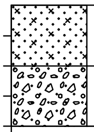
Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP65**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	
	Slightly moist to moist, brown, loose, intact, silty SAND with roots. Aeolian
0.20	
	Brown, red, grey and off-white, matrix supported, angular to sub-angular fine to medium, ferruginised and calcritised gravel in a matrix of slightly moist silty sand. Overall consistency is medium dense to dense. Terrace gravels
0.40	

NOTES:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:

INCLINATION:
DIAM:
DATE DRILLED: 7/27/2020
DATE PROFILED: 7/27/2020

ELEVATION:
X COORD: - 67046
Y COORD: - 3494221

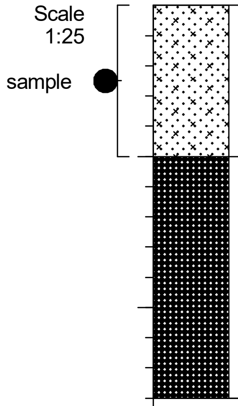
EBENHAESER SCHEME.GPJ

HOLE No: **E-TP65**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP66**
Sheet 1 of 1

JOB NUMBER: **113834**



0.00	Moist, brown , medium dense, intact, silty SAND with roots. Aeolian
0.50	Off-white and brown, moderately cemented calcrete gravel (nodules) in a matrix of slightly moist silty sand. Overall consistency is dense to very dense. Pedogenic material
1.30	

<u>NOTES</u>:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. Small bag between 0.0-0.5m.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	Bell 315SK TLB	DIAM:		X COORD:	- 67272
PROFILED BY:	S. Nyathi and M Sikwe	DATE DRILLED:	7/27/2020	Y COORD:	- 3494001
TYPE SET BY:		DATE PROFILED:	7/27/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP66**

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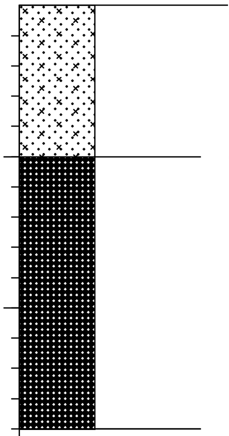
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP67**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Moist, brown , medium dense, intact, silty SAND with roots. Aeolian
0.50	Slightly moist, brown and off-white, dense to very dense, micro-shattered, cemented SAND with calcrete nodules and gravel. Pedogenic material
1.40	

NOTES:

1. Refusal on hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 67483
PROFILED BY:	S. Nyathi and M Sikwe	*DATE DRILLED:*	7/27/2020	*Y COORD:*	- 3493799
TYPE SET BY:		*DATE PROFILED:*	7/27/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP67**

aurecon **Department of Water and Sanitation**
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP68**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25

0.00 0.30	Brown and off-white, highly cemented, very soft rock. Hardpan calcrete

NOTES:

1. Refusal on hardpan calcrete, immediate surroundings are hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/27/2020
DATE PROFILED: 7/27/2020

ELEVATION:
X COORD: - 67733
Y COORD: - 3493672

HOLE No: **E-TP68**

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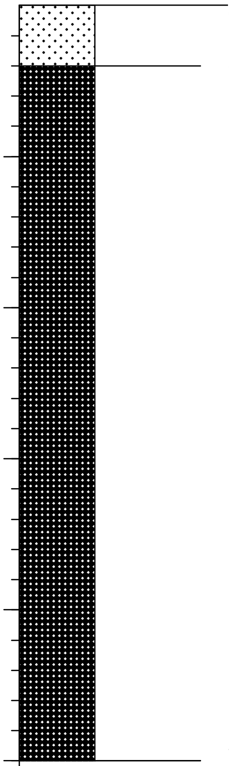
Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP69**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Dry, brown, loose, intact, SAND. Aeolian
0.20	Brown and off-white, highly cemented, very dense to very soft rock. Hardpan calcrete
2.50	

NOTES:

1. Refusal on hardpan calcrete, logged a cut face of a borrow pit.
2. No sample taken.
3. No seepage.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 68045
PROFILED BY:	S. Nyathi and M Sikwe	*DATE DRILLED:*	7/27/2020	*Y COORD:*	- 3493652
TYPE SET BY:		*DATE PROFILED:*	7/27/2020		

EBENHAESER SCHEME.GPJ

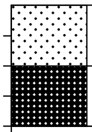
HOLE No: **E-TP69**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP70**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Moist, brown, loose, intact, SAND. Aeolian
0.20	Brown and off-white, highly cemented, very soft rock. Hardpan calcrete
0.40	

<u>NOTES</u>:

1. Refusal on hardpan calcrete, immediate surroundings are hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	Bell 315SK TLB	DIAM:		X COORD:	- 68344
PROFILED BY:	S. Nyathi and M Sikwe	DATE DRILLED:	7/27/2020	Y COORD:	- 3493589
TYPE SET BY:		DATE PROFILED:	7/27/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP70**

Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

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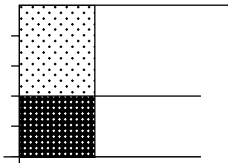
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP71**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Moist, brown, medium dense, intact, SAND. Aeolian
0.30	Brown and off-white, highly cemented, very soft rock. Hardpan calcrete
0.50	

<u>NOTES</u>:

1. Refusal on hardpan calcrete, immediate surroundings are hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 68543
PROFILED BY:	S. Nyathi and M Sikwe	*DATE DRILLED:*	7/28/2020	*Y COORD:*	- 3493553
TYPE SET BY:		*DATE PROFILED:*	7/28/2020		
	EBENHAESER SCHEME.GPJ				

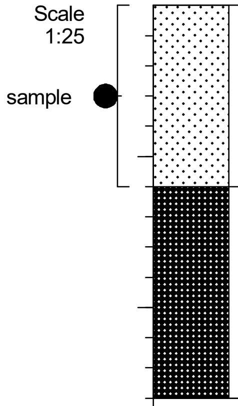
HOLE No: **E-TP71**

Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP72**
Sheet 1 of 1

JOB NUMBER: **113834**



0.00	Moist, brown, medium dense, intact, SAND. Aeolian
0.60	Off-white and brown, clast supported calcrete nodules and gravel occassionally cobbles in a matrix of slightly moist sand. Overall consistency is dense to very dense. Pedogenic material
1.30	

NOTES:

1. Refusal on hardpan calcrete, immediate surroundings are hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. Small bag between 0.0-0.6m.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 68701
PROFILED BY:	S. Nyathi and M Sikwe	*DATE DRILLED:*	7/28/2020	*Y COORD:*	- 3493776
TYPE SET BY:		*DATE PROFILED:*	7/28/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP72**

Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

Department of Water and Sanitation

Bridging Study Clanwilliam Dam

Ebenhaeser Scheme

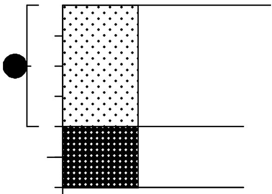
HOLE No: **E-TP73**

Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25

sample ●



Depth	Description
0.00	Moist, brown, loose, intact, SAND. Aeolian
0.40	Off-white and brown, clast supported calcrete nodules and gravel occassionally cobbles in a matrix of slightly moist sand. Overall consistency very dense. Pedogenic material
0.60	

NOTES:

1. Refusal on hardpan calcrete, immediate surroundings are hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. Small bag between 0.0-0.4m.

CONTRACTOR: DWS

MACHINE: Bell 315SK TLB

PROFILED BY: S. Nyathi and M Sikwe

TYPE SET BY:

EBENHAESER SCHEME.GPJ

INCLINATION:

DIAM:

DATE DRILLED: 7/28/2020

DATE PROFILED: 7/28/2020

ELEVATION:

X COORD: - 68925

Y COORD: - 3493651

HOLE No: **E-TP73**

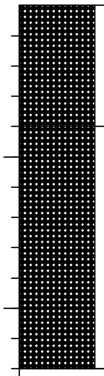
Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP74**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Off-white and brown, moderately cemented calcrete gravel (nodules) in a matrix of slightly moist silty sand. Overall consistency is dense to very dense. Pedogenic material
0.40	Off-white and brown, highly cemented, very soft rock. Hardpan calcrete
1.20	

<u>NOTES</u>:

1. Logged open pit.
2. Sidewalls stable.
3. No sample taken.
4. No seepage.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 69167
PROFILED BY:	S. Nyathi and M Sikwe	*DATE DRILLED:*	7/28/2020	*Y COORD:*	- 3493862
TYPE SET BY:		*DATE PROFILED:*	7/28/2020		

EBENHAESER SCHEME.GPJ

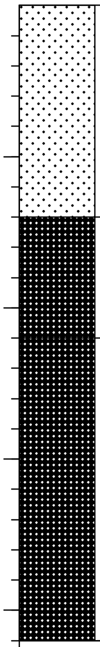
HOLE No: **E-TP74**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP75**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Dry, brown, dense, intact, SAND. Aeolian
0.70	Dry, brown speckled black, dense to very dense, intact, sand with ferricrete nodules (gravel). Pedogenic material
1.10	Off-white and brown, highly cemented, very soft rock. Hardpan calcrete
2.10	

NOTES:

1. Logged open pit.
2. Sidewalls stable.
3. No sample taken.
4. No seepage.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/28/2020
DATE PROFILED: 7/28/2020

ELEVATION:
X COORD: - 69307
Y COORD: - 3494029

HOLE No: **E-TP75**

Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

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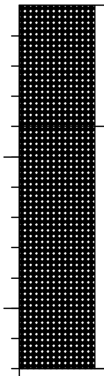
Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP76**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Off-white and brown, moderately cemented calcrete gravel (nodules) in a matrix of slightly moist silty sand. Overall consistency is dense to very dense. Pedogenic material
0.40	Off-white and brown, highly cemented, very soft rock. Hardpan calcrete
1.20	

<u>NOTES</u>:

1. Logged open pit.
2. Sidewalls stable.
3. No sample taken.
4. No seepage.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 69411
PROFILED BY:	S. Nyathi and M Sikwe	*DATE DRILLED:*	7/28/2020	*Y COORD:*	- 3494269
TYPE SET BY:		*DATE PROFILED:*	7/28/2020		

EBENHAESER SCHEME.GPJ

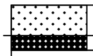
HOLE No: **E-TP76**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP77**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00
0.15
0.10

Moist, brown, loose, intact, SAND. Aeolian

Brown, black and red, highly cemented, very soft rock. Hardpan ferricrete

NOTES:

1. Refusal on hardpan calcrete, immediate surroundings are hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:

INCLINATION:
DIAM:
DATE DRILLED: 7/28/2020
DATE PROFILED: 7/28/2020

ELEVATION:
X COORD: - 69585
Y COORD: - 3494570

HOLE No: **E-TP77**

EBENHAESER SCHEME.GPJ

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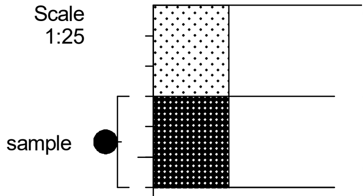
Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP78**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



Depth	Description
0.00	Moist, brown, medium dense, intact, SAND. Aeolian
0.30	Off-white and brown, clast supported calcrete nodules and gravel occassionally cobbles in a matrix of slightly moist sand. Overall consistency is very dense. Pedogenic material
0.60	

NOTES:

1. Refusal on hardpan calcrete, immediate surroundings are hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. Small bag between 0.3-0.6m.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:

INCLINATION:
DIAM:
DATE DRILLED: 7/28/2020
DATE PROFILED: 7/28/2020

ELEVATION:
X COORD: - 69792
Y COORD: - 3494858

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP78**

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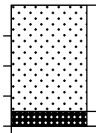
Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP79**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Moist, brown, loose, intact, SAND. Aeolian
0.40	
0.35	Brown and off-white, highly cemented, very soft rock. Hardpan calcrete

NOTES:

1. Refusal on hardpan calcrete, immediate surroundings are hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	Bell 315SK TLB	*DIAM:*		*X COORD:*	- 69985
PROFILED BY:	S. Nyathi and M Sikwe	*DATE DRILLED:*	7/28/2020	*Y COORD:*	- 3495017
TYPE SET BY:		*DATE PROFILED:*	7/28/2020		

EBENHAESER SCHEME.GPJ

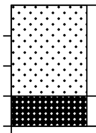
HOLE No: **E-TP79**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP80**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25



0.00	Moist, brown, loose, intact, SAND. Aeolian
0.30 0.40	Brown and off-white, highly cemented, very soft rock. Hardpan calcrete

NOTES:

1. Refusal on hardpan calcrete, immediate surroundings are hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/28/2020
DATE PROFILED: 7/28/2020

ELEVATION:
X COORD: - 70244
Y COORD: - 3495135

HOLE No: **E-TP80**

Report ID: _ZA TRAIL PIT LOG || Project: EBENHAESER SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: October 1, 2020

aurecon **Department of Water and Sanitation**
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

HOLE No: **E-TP81**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale
1:25

Depth	Description
0.00 0.10	Off-white and brown, highly cemented, very soft rock. Hardpan calcrete

NOTES:

1. Refusal on hardpan calcrete, immediate surroundings are hardpan calcrete.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR: DWS
MACHINE: Bell 315SK TLB
PROFILED BY: S. Nyathi and M Sikwe
TYPE SET BY:
EBENHAESER SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/28/2020
DATE PROFILED: 7/28/2020

ELEVATION:
X COORD: - 70526
Y COORD: - 3495248

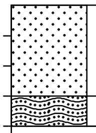
HOLE No: **E-TP81**

HOLE No: E-TP82
Sheet 1 of 1

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Ebenhaeser Scheme

JOB NUMBER: **113834**

Scale
1:25



0.00

Moist, brown, loose, intact, SAND. Aeolian

0.30
0.40

Off-white, grey and brown, highly weathered, fine grained, laminated, very soft rock. Calcritised schist

NOTES:

1. Refusal on calcritised schist, immediate surroundings on calcritised schist.
2. No groundwater seepage was encountered.
3. Sidewall stable.
4. No sample taken.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	Bell 315SK TLB	DIAM:		X COORD:	- 70817
PROFILED BY:	S. Nyathi and M Sikwe	DATE DRILLED:	7/28/2020	Y COORD:	- 3495341
TYPE SET BY:		DATE PROFILED:	7/28/2020		

EBENHAESER SCHEME.GPJ

HOLE No: **E-TP82**

Appendix D
DCP Test Results

ZUTARI

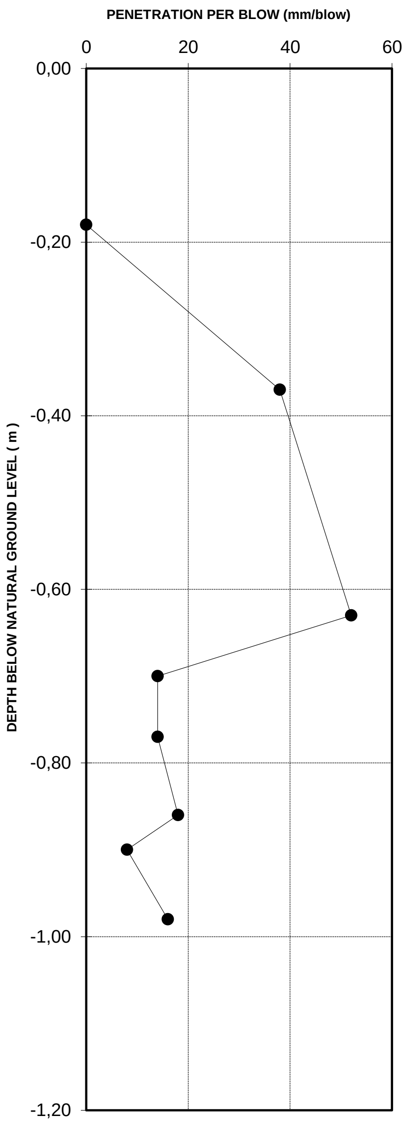
Ground and Pavement Engineering

DYNAMIC CONE PENETRATION TEST

ZUTARI IMPACT. ENGINEERED.

PROJECT	Bridging Study Clanwilliam Dam
PROJECT NUMBER	113834
TEST LOCATION	E TP43
STARTING DEPTH FROM N.G.L. (m)	0
DATE	

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION	ALLOWABLE BEARING PRESSURE**	GRAPH
0	180	-0,180	#DIV/0!	#DIV/0!	0	
5	370	-0,370	38	3	57	
10	630	-0,630	52	2	42	
15	700	-0,700	14	7	154	
20	770	-0,770	14	7	154	
25	860	-0,860	18	6	120	
30	900	-0,900	8	13	270	
35	980	-0,980	16	6	135	



** From " RULE OF THUMB METHOD" by I S VENTER

ZUTARI

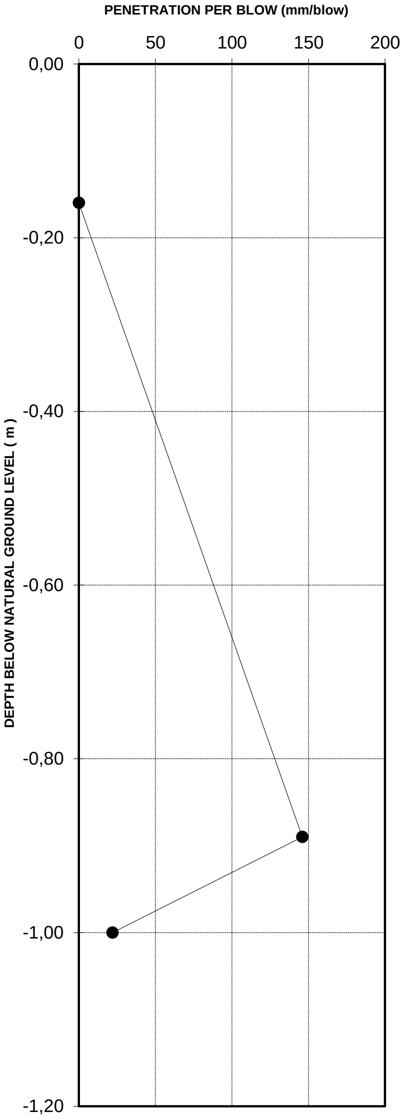
Ground and Pavement Engineering

DYNAMIC CONE PENETRATION TEST

PROJECT	Bridging Study Clanwilliam Dam
PROJECT NUMBER	113834
TEST LOCATION	E TP49
STARTING DEPTH FROM N.G.L. (m)	0
DATE	

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION	ALLOWABLE BEARING PRESSURE**
0	160	-0,160	#DIV/0!	#DIV/0!	0
5	890	-0,890	146	1	15
10	1000	-1,000	22	5	98

GRAPH



** From " RULE OF THUMB METHOD" by I S VENTER

ZUTARI

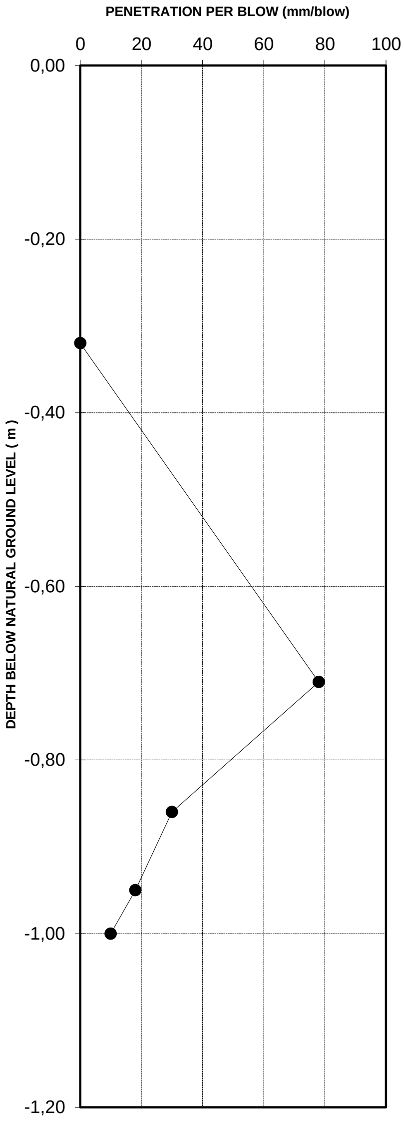
Ground and Pavement Engineering

DYNAMIC CONE PENETRATION TEST

PROJECT	Bridging Study Clanwilliam Dam
PROJECT NUMBER	113834
TEST LOCATION	E TP50
STARTING DEPTH FROM N.G.L. (m)	0
DATE	

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION	ALLOWABLE BEARING PRESSURE**
0	320	-0,320	#DIV/0!	#DIV/0!	0
5	710	-0,710	78	1	28
10	860	-0,860	30	3	72
15	950	-0,950	18	6	120
20	1000	-1,000	10	10	216

GRAPH



** From " RULE OF THUMB METHOD" by I S VENTER

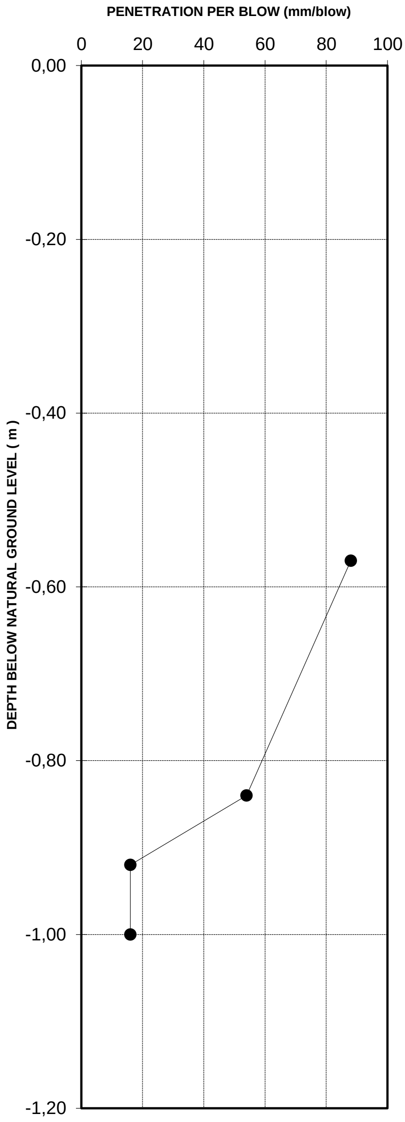
ZUTARI

Ground and Pavement Engineering

DYNAMIC CONE PENETRATION TEST

PROJECT	Bridging Study Clanwilliam Dam
PROJECT NUMBER	113834
TEST LOCATION	E TP53
STARTING DEPTH FROM N.G.L. (m)	0
DATE	

NUMBER OF BLOWS	PENETRATION DEPTH [mm]	DEPTH FROM N.G.L. [m]	PENETRATION RATE [mm / blow]	BLOWS/ 100 mm PENETRATION	ALLOWABLE BEARING PRESSURE**	GRAPH
0	130	-0,130			0	
5	570	-0,570	88	1	25	
10	840	-0,840	54	2	40	
15	920	-0,920	16	6	135	
20	1000	-1,000	16	6	135	



** From " RULE OF THUMB METHOD" by I S VENTER

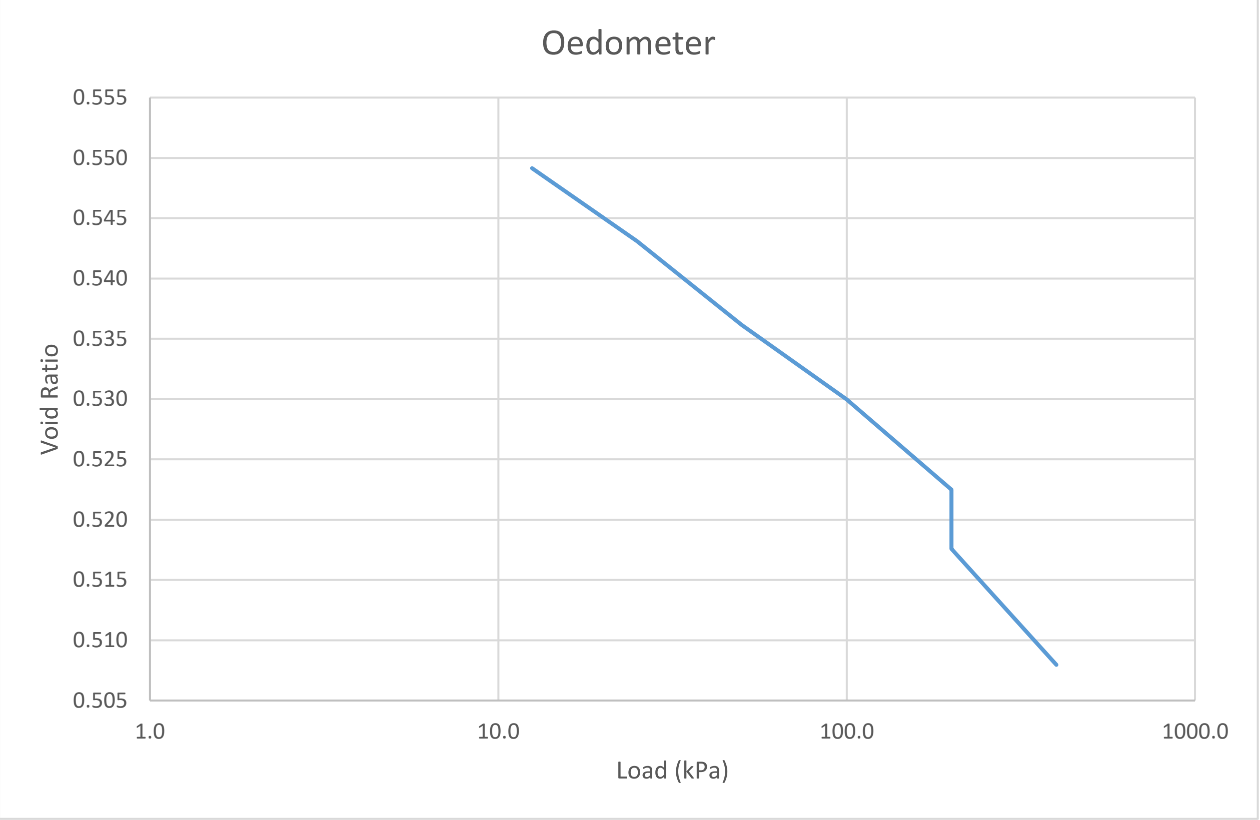
Appendix E
Laboratory Test Results

Oedometer Collapse Test

Sample Detail		Initial	Final
Height	(mm)	20.3	19.7
Diameter	(mm)	63.5	63.5
Weight	(g)	117.9	123.1
Moisture	(%)	8.6	13.4
Dry Density	(Mg/m^3)	1.69	1.74
Bulk Density	(Mg/m^3)	1.83	1.97
Void Ratio		0.551	0.508
Particle Density	(Mg/m^3)	2.62	

Collapse Results	
Collapse Potential	0.3 %

Load (kPa)	Height (mm)	Void Ratio
12.5	20.276	0.549
25.0	20.197	0.543
50.0	20.106	0.536
100.0	20.025	0.530
200.0	19.927	0.522
200.0	19.863	0.518
400.0	19.737	0.508



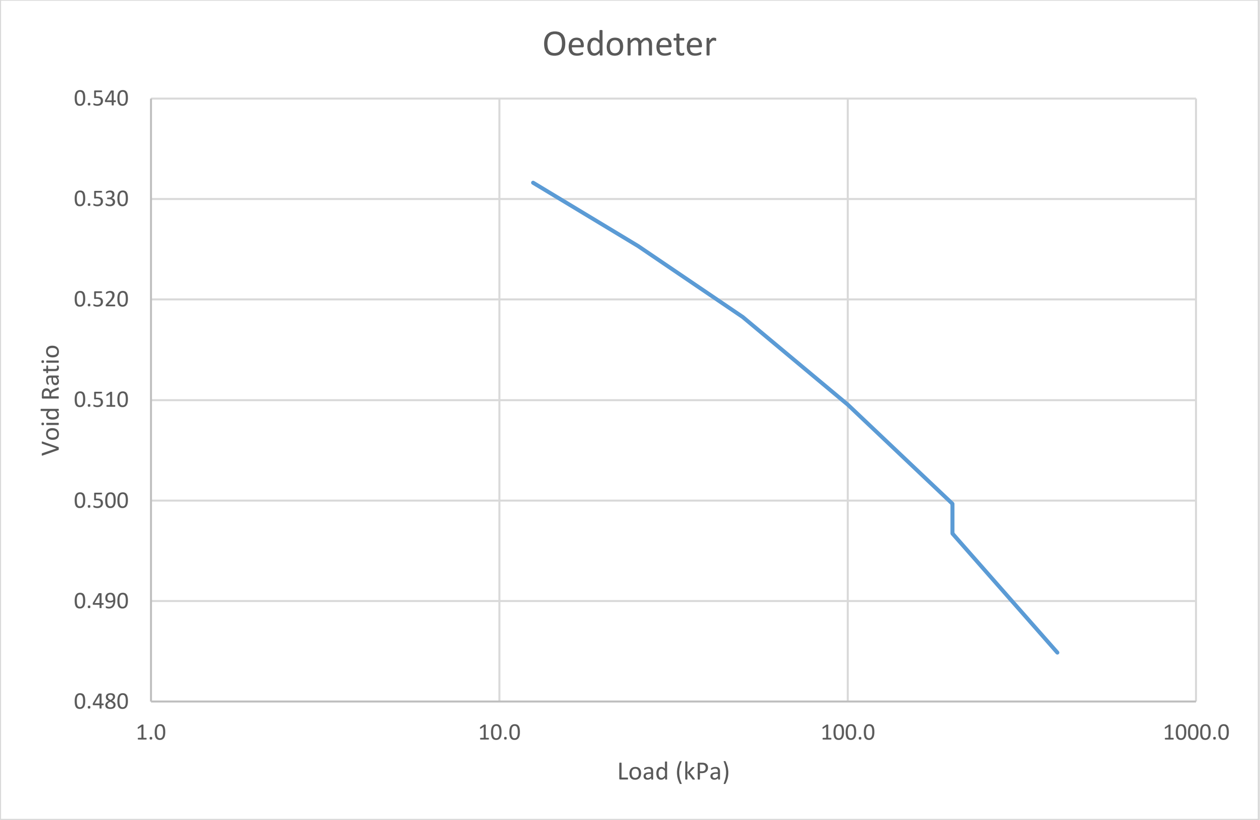
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 5: 1990: Clause 3	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech
	Site Reference Jobfile Client	 SWG00088 Zutari	Test Date 11/08/2020 Sample E-TP15_0.0-1.4m Borehole Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC

Oedometer Collapse Test

Sample Detail		Initial	Final
Height	(mm)	20.3	19.6
Diameter	(mm)	63.5	63.5
Weight	(g)	118.4	122
Moisture	(%)	7.9	12.1
Dry Density	(Mg/m^3)	1.71	1.76
Bulk Density	(Mg/m^3)	1.84	1.97
Void Ratio		0.541	0.485
Particle Density	(Mg/m^3)	2.63	

Collapse Results	
Collapse Potential	0.2 %

Load (kPa)	Height (mm)	Void Ratio
12.5	20.177	0.532
25.0	20.094	0.525
50.0	20.001	0.518
100.0	19.886	0.510
200.0	19.756	0.500
200.0	19.717	0.497
400.0	19.561	0.485



Test Method	BS1377 - 5: 1990: Clause 3	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
Site Reference		Test Date	12/08/2020
Jobfile	SWG00088	Sample	E-TP33_0.0-1.6m
Client	Zutari	Borehole	Clanwilliam Bridging Study
Operator:FC	Checked: FC	Approved: FC	

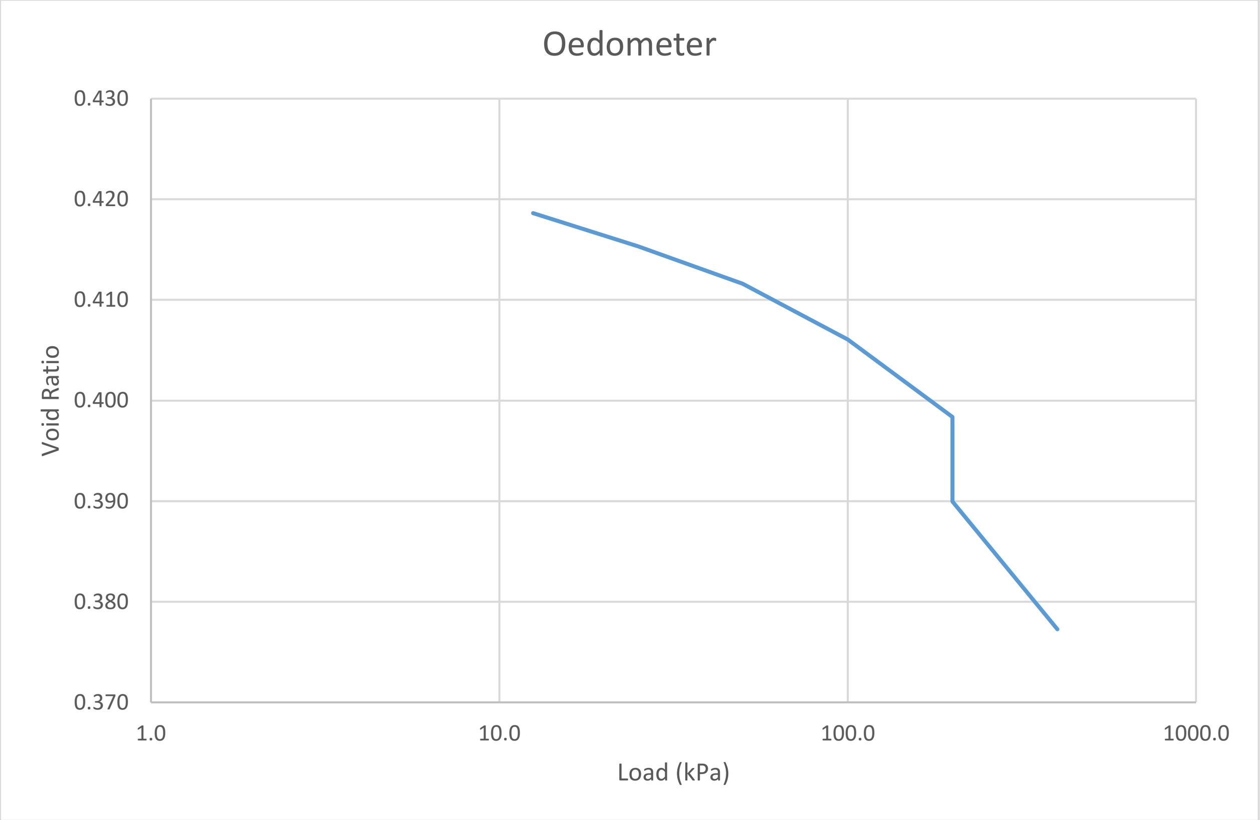
STEYN-WILSON GEOTECHNICAL

Oedometer Collapse Test

Sample Detail		Initial	Final
Height	(mm)	20.3	19.6
Diameter	(mm)	63.5	63.5
Weight	(g)	123.8	129.9
Moisture	(%)	5.4	12.6
Dry Density	(Mg/m^3)	1.83	1.85
Bulk Density	(Mg/m^3)	1.93	2.09
Void Ratio		0.423	0.377
Particle Density	(Mg/m^3)	2.60	

Collapse Results	
Collapse Potential	0.6 %

Load (kPa)	Height (mm)	Void Ratio
12.5	20.236	0.419
25.0	20.189	0.415
50.0	20.136	0.412
100.0	20.057	0.406
200.0	19.947	0.398
200.0	19.827	0.390
400.0	19.646	0.377



STEYN-WILSON GEOTECHNICAL	Test Method BS1377 - 5: 1990: Clause 3	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference	Test Date	13/08/2020
	Jobfile SWG00088	Sample	E-TP57_0.5-1.9m
	Client Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC

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DOUBLE HYDROMETER TEST ASTM D4221
CRUMB TEST ASTM D6572
PINHOLE TEST ASTM D4649

CLIENT: Zutari
DATE: 07/09/2020
JOB NO.: SWG00088
PROJECT: Clanwilliam Bridging Study

		Double Hydrometer			Crumb Test	Pinhole Test
Sample Details	*Depth (m):*	*% Passing 0.005mm*		*% Dispersion*	*Dispersive Classification*	*Dispersive Classification*
		ASTM D4221	*ASTM D422*			
E TP45	**0.5-1.1**	**2**	**9**	**19.5**	*	**Non Dispersive**
E TP46	**0.0-0.6**	**0**	**8**	**0.0**	*	**Non Dispersive**
E TP53	**0.0-1.5**	**0**	**3**	**0.0**	*	**Non Dispersive**
E TP57	**0.5-1.9**	**2**	**10**	**20.0**	*	**Non Dispersive**
E TP28	**0.0-2.5**	**0**	**2**	**0.0**	*	**Non Dispersive**
E TP38	**0.0-0.9**	**0**	**2**	**0.0**	*	**Non Dispersive**
E TP33	**0.0-1.6**	**0**	**4**	**0.0**	*	**Non Dispersive**
E TP07	**0.3-3.0**	**10**	**33**	**30.7**	**Dispersive**	**Dispersive**
E TP09	**0.0-3.0**	**1**	**4**	**25.0**	*	**Non Dispersive**
E TP24ADD	**0.0-2.2**	**0**	**1**	**0.0**	*	**Non Dispersive**
E TP14	**0.0-1.7**	**0**	**2**	**0.0**	*	**Non Dispersive**
E TP15	**0.0-1.4**	**0**	**10**	**0.0**	*	**Non Dispersive**
E TP11	**0.0-1.1**	**0**	**4**	**0.0**	*	**Non Dispersive**
E TP16	**0.3-0.5**	**0**	**4**	**0.0**	*	**Non Dispersive**
E TP10	**1.0-2.0**	**4**	**21**	**19.0**	**Slightly Dispersive**	**Slightly Dispersive**

* Crumb test is not applicable for samples with 12% or less particles passing 0.005mm and having a plasticity index less than or equal to 8

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FALLING HEAD PERMEABILITY TEST REPORT - TEST METHOD: ASTM D2434 & KH HEAD

CLIENT: **ZUTARI**
DATE: **25/08/2020**
JOB NO.: **SWG00088**
PROJECT: **CLANWILLIAM BRIDGING STUDY**

Sample Details		Remould Details (MOD)								Tests						
E TP09		Specified				Actual				Time						
Sample no.	Depth(m):	Dry Density:		%:	OMC:	Dry density:		%	Moisture Content:	Test:	H1 (mm):	H2 (mm):	h	m	s	Permeability (cm/s)
300	0.0-3.0	1859	kg/m^3	98	11.6	1778	kg/m^3	95.6	11.6	1	**1550**	**1313**	1	39	18	1.7168E-05
										2	**1313**	**1180**	1	24	45	1.2947E-05
										3	**1180**	**1060**	1	47	23	1.0260E-05
													Average:			**1.3458E-05**

E TP14		Specified				Actual				Time						
Sample no.	Depth(m):	Dry Density:		%:	OMC:	Dry density:		%	Moisture Content:	Test:	H1 (cm):	H2 (cm):	h	m	s	Permeability (cm/s)
303	0.0-1.7	1744	kg/m^3	98	10.8	1693	kg/m^3	97.1	10.8	1	**1550**	**748**	0	1	25	5.2981E-03
										2	**1550**	**740**	0	1	24	5.4403E-03
										3	**1550**	**744**	0	1	22	5.5324E-03
													Average:			**5.4236E-03**

E TP15		Specified				Actual				Time						
Sample no.	Depth(m):	Dry Density:		%:	OMC:	Dry density:		%	Moisture Content:	Test:	H1 (cm):	H2 (cm):	h	m	s	Permeability (cm/s)
304	0.0-1.4	2023	kg/m^3	98	10.4	1906	kg/m^3	94.2	10.4	1	**1462**	**1435**	3	8	31	1.0172E-06
										2	**1435**	**1410**	3	3	0	9.8794E-07
										3	**1410**	**1367**	5	47	12	9.1762E-07
													Average:			**9.7424E-07**

E TP28		Specified				Actual				Time						
Sample no.	Depth(m):	Dry Density:		%:	OMC:	Dry density:		%	Moisture Content:	Test:	H1 (cm):	H2 (cm):	h	m	s	Permeability (cm/s)
308	0.0-2.5	1821	kg/m^3	98	10.5	1749	kg/m^3	96.0	10.5	1	**1550**	**744**	0	4	12	1.7973E-03
										2	**1555**	**745**	0	3	52	1.9572E-03
										3	**1560**	**747**	0	3	44	2.0286E-03
													Average			**1.9277E-03**

E TP46		Specified				Actual				Time						
Sample no.	Depth(m):	Dry Density:		%:	OMC:	Dry density:		%	Moisture Content:	Test:	H1 (cm):	H2 (cm):	h	m	s	Permeability (cm/s)
312	0.0-0.6	1741	kg/m^3	98	11.6	1655	kg/m^3	95.1	11.6	2	**1550**	**745**	0	1	33	4.8543E-03
										3	**1550**	**750**	0	1	34	4.7588E-03
										1	**1550**	**749**	0	1	33	4.8188E-03
													Average			**4.8107E-03**

E TP53		Specified				Actual				Time						
Sample no.	Depth(m):	Dry Density:		%:	OMC:	Dry density:		%	Moisture Content:	Test:	H1 (cm):	H2 (cm):	h	m	s	Permeability (cm/s)
313	0.0-1.5	1771	kg/m^3	98	11.1	1730	kg/m^3	97.7	11.1	3	**1550**	**742**	0	4	2	1.8820E-03
										1	**1550**	**741**	0	3	55	1.9416E-03
										2	**1550**	**741**	0	3	50	1.9838E-03
													Average			**1.9358E-03**

E TP10		Specified				Actual				Time						
Sample no.	Depth(m):	Dry Density:		%:	OMC:	Dry density:		%	Moisture Content:	Test:	H1 (cm):	H2 (cm):	h	m	s	Permeability (cm/s)
301	1.0-2.0	1967	kg/m^3	98	10.3	1916	kg/m^3	97.4	10.3	1	**1565**	**1550**	1	2	17	6.5082E-08
										2	**1550**	**1538**	1	8	57	4.7442E-08
										3	**1538**	**1527**	1	9	52	4.3240E-08
													Average			**5.1921E-08**

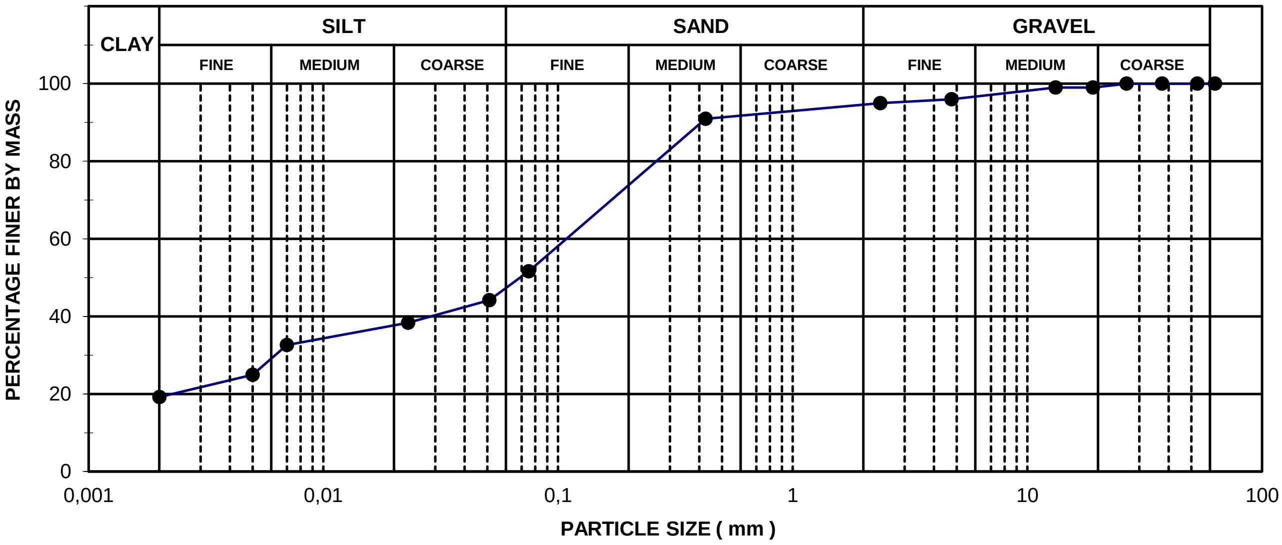
E TP17		Specified				Actual				Time						
Sample no.	Depth(m):	Dry Density:		%:	OMC:	Dry density:		%	Moisture Content:	Test:	H1 (cm):	H2 (cm):	h	m	s	Permeability (cm/s)
306	0.0-1.7	1741	kg/m^3	98	10.5	1686	kg/m^3	96.9	10.5	1	**1550**	**745**	0	1	20	5.6563E-03
										2	**1550**	**745**	0	1	19	5.7279E-03
										3	**1550**	**743**	0	1	19	5.7489E-03
													Average			**5.7111E-03**

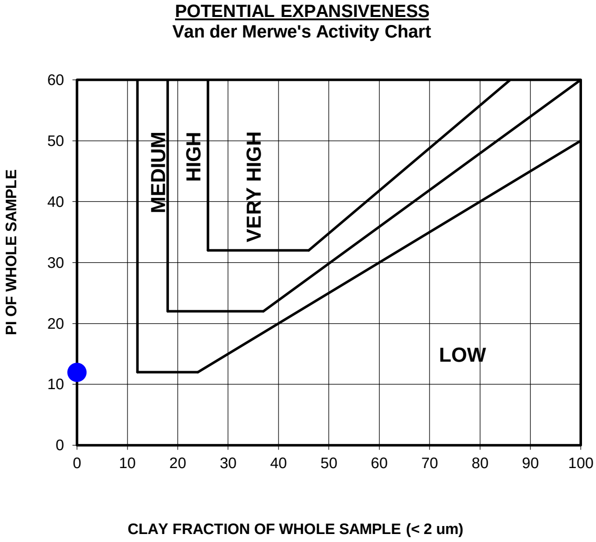
FOUNDATION INDICATOR TEST RESULTS

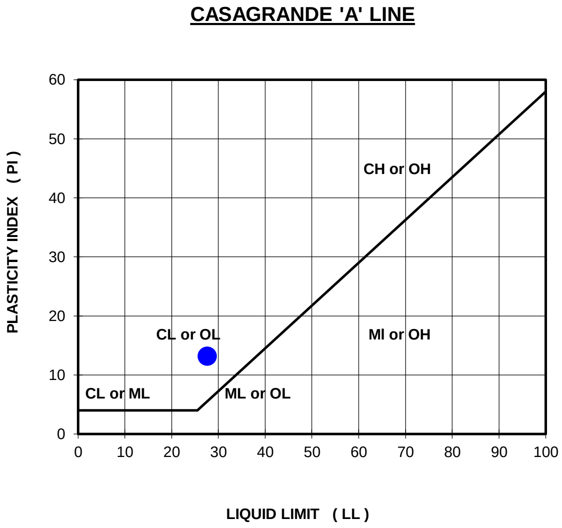
TEST LOCATION	EB TP 07	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13944	PROJECT NUMBER	113834
DEPTH	0,3-3,00 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**91**	Liquid limit	(%)	**27,6**	% Gravel	**5**
53,000	**100**	0,075	**52**	Plastic limit	(%)	**14**	% Sand	**43**
37,500	**100**	0,051	**44**	Plasticity Index	(%)	**13**	% Silt	**32**
26,500	**100**	0,023	**38**	Weighted PI	(%)	**12**	% Clay	**19**
19,000	**99**	0,007	**33**	Linear Shrinkage	(%)	**6,3**	Activity	**0,7**
13,200	**99**	0,002	**19**	Grading Modulus		**0,62**	Unified Classification	**CL**
4,750	**96**	0,000	**0**	Uniformity coefficient		**75**	TRB Classification	**A - 6**
2,360	**95**	0,000	**0**	Coefficient of curvature		**0,4**		

PARTICLE SIZE DISTRIBUTION







FOUNDATION INDICATOR TEST RESULTS

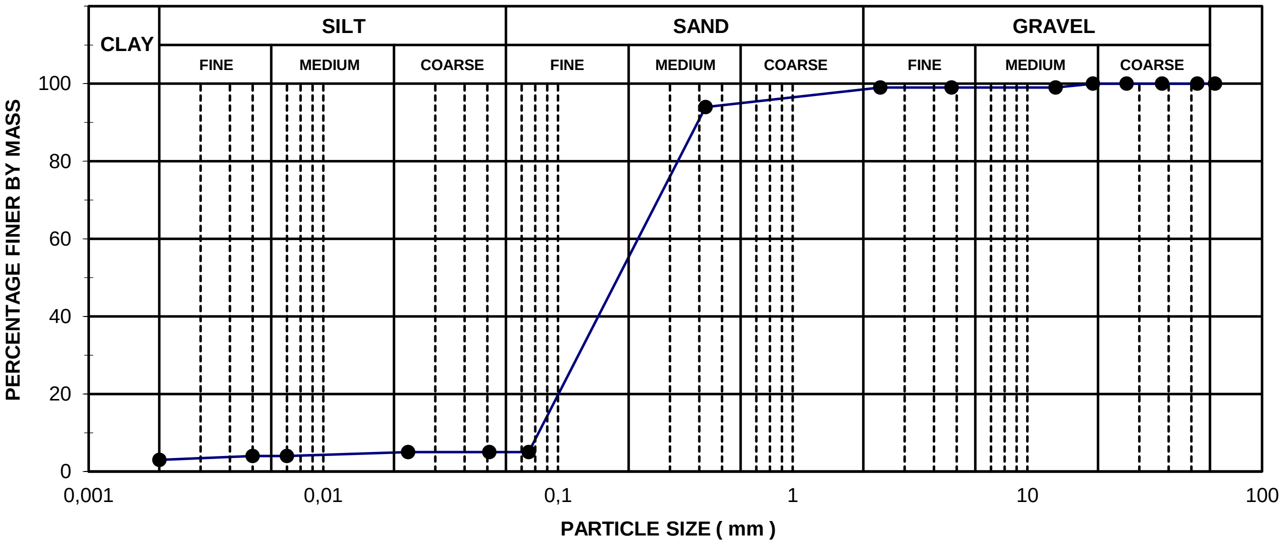
TEST LOCATION	EB TP 09	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13945	PROJECT NUMBER	113834
DEPTH	0,0-3,00 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS			
Sieve (mm)	% Passing	Sieve (mm)	% Passing
63,000	**100**	0,425	**94**
53,000	**100**	0,075	**5**
37,500	**100**	0,051	**5**
26,500	**100**	0,023	**5**
19,000	**100**	0,007	**4**
13,200	**99**	0,002	**3**
4,750	**99**	0,000	**0**
2,360	**99**	0,000	**0**

ATTERBERG LIMITS		
Liquid limit	(%)	**0,0**
Plastic limit	(%)	**0**
Plasticity Index	(%)	**0**
Weighted PI	(%)	**0**
Linear Shrinkage	(%)	**0,0**
Grading Modulus		**1,02**
Uniformity coefficient		**3**
Coefficient of curvature		**1,1**

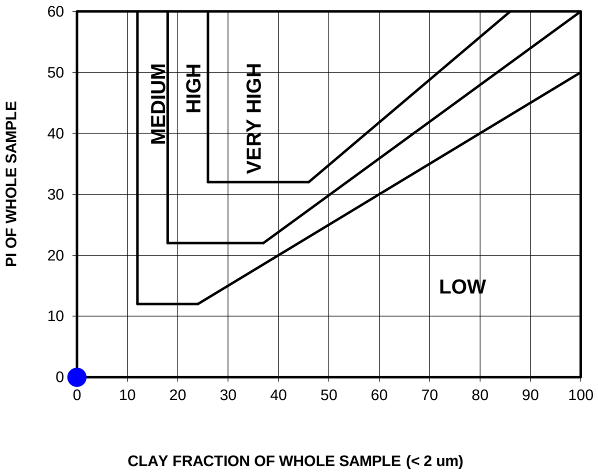
SOIL CLASSIFICATION	
% Gravel	**1**
% Sand	**94**
% Silt	**2**
% Clay	**3**
Activity	**0,0**
Unified Classification	**SP-SM**
TRB Classification	**A - 3**

PARTICLE SIZE DISTRIBUTION

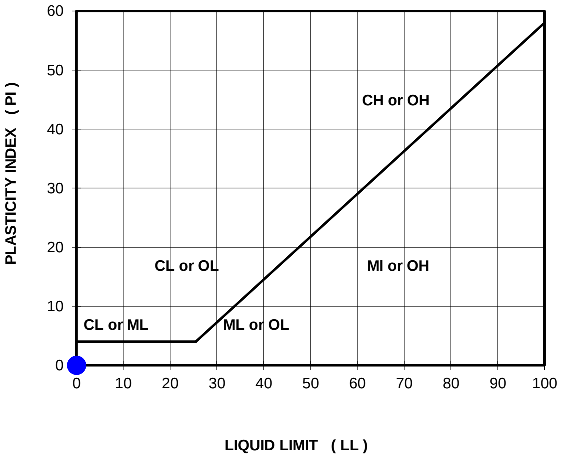


POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE

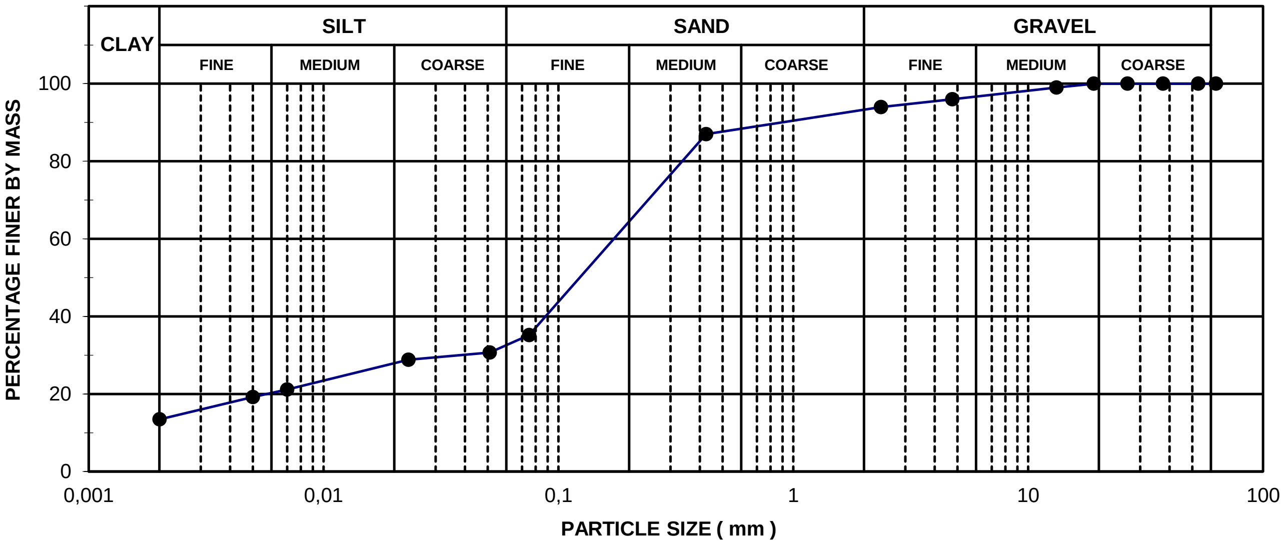


FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	EB TP 10	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13953	PROJECT NUMBER	113834
DEPTH	1,00-2,00 m	SITE	Ebenhaeser Scheme

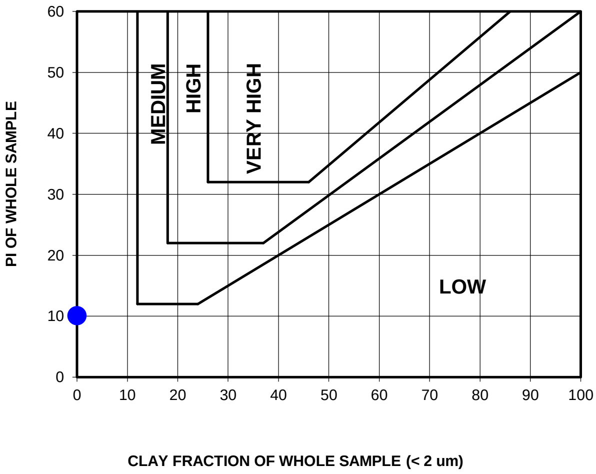
SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**87**	Liquid limit	(%)	**35,0**	% Gravel	**6**
53,000	**100**	0,075	**35**	Plastic limit	(%)	**23**	% Sand	**59**
37,500	**100**	0,051	**31**	Plasticity Index	(%)	**12**	% Silt	**22**
26,500	**100**	0,023	**29**	Weighted PI	(%)	**10**	% Clay	**13**
19,000	**100**	0,007	**21**	Linear Shrinkage	(%)	**5,4**	Activity	**0,9**
13,200	**99**	0,002	**13**	Grading Modulus		**0,84**	Unified Classification	**SC**
4,750	**96**	0,000	**0**	Uniformity coefficient		**121**	TRB Classification	**A - 6**
2,360	**94**	0,000	**0**	Coefficient of curvature		**3,9**		

PARTICLE SIZE DISTRIBUTION



POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



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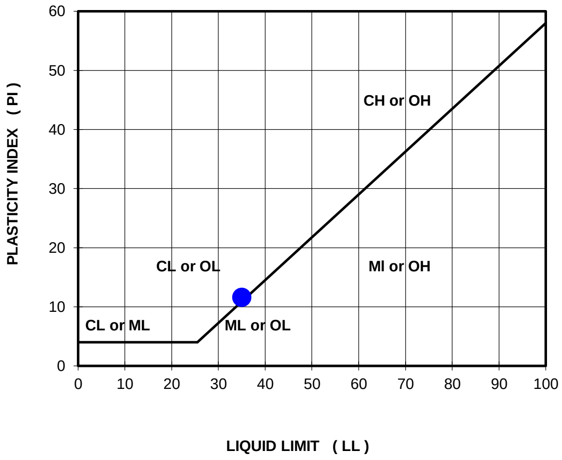

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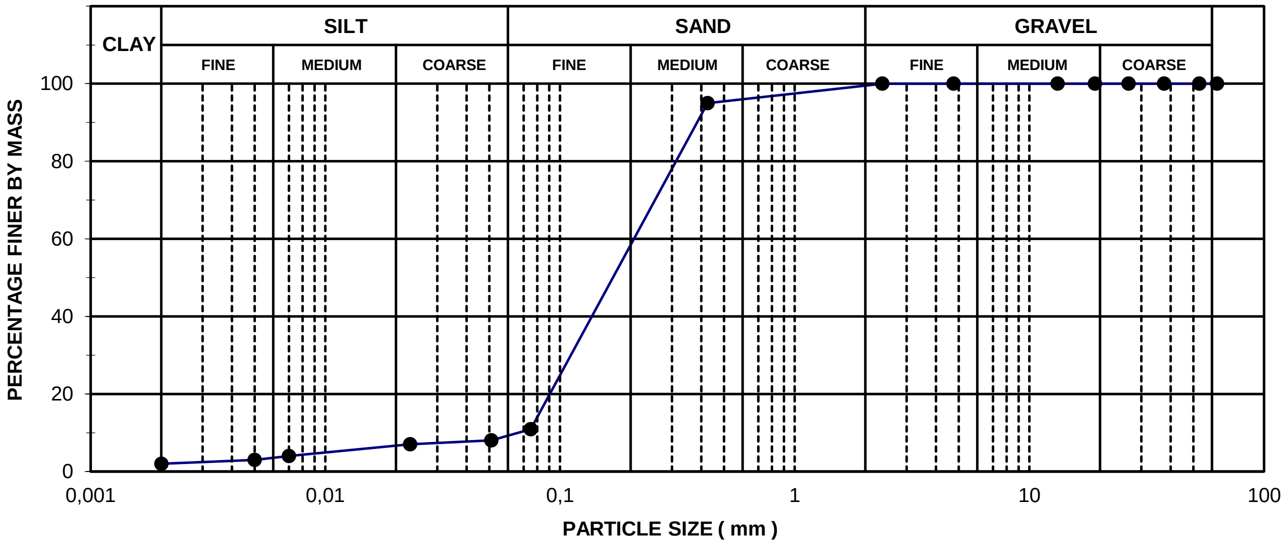
FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	EB TP 11	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13981	PROJECT NUMBER	113834
DEPTH	1,10-1,40 m	SITE	Ebenhaeser Scheme

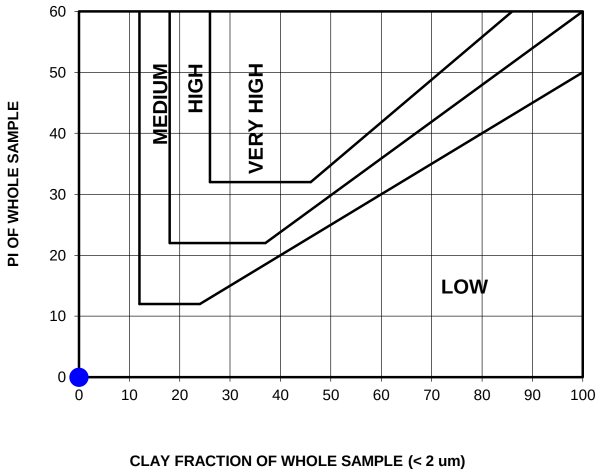
SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**95**	Liquid limit	(%)	**0,0**	% Gravel	**0**
53,000	**100**	0,075	**11**	Plastic limit	(%)	**0**	% Sand	**89**
37,500	**100**	0,051	**8**	Plasticity Index	(%)	**0**	% Silt	**9**
26,500	**100**	0,023	**7**	Weighted PI	(%)	**0**	% Clay	**2**
19,000	**100**	0,007	**4**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**100**	0,002	**2**	Grading Modulus		**0,94**	Unified Classification	**SP-SM**
4,750	**100**	0,000	**0**	Uniformity coefficient		**4**	TRB Classification	**A - 2 - 4**
2,360	**100**	0,000	**0**	Coefficient of curvature		**1,3**		

PARTICLE SIZE DISTRIBUTION



POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



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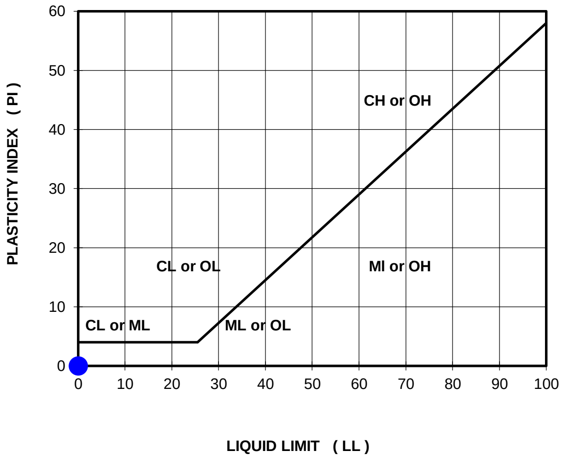


FOUNDATION INDICATOR TEST RESULTS

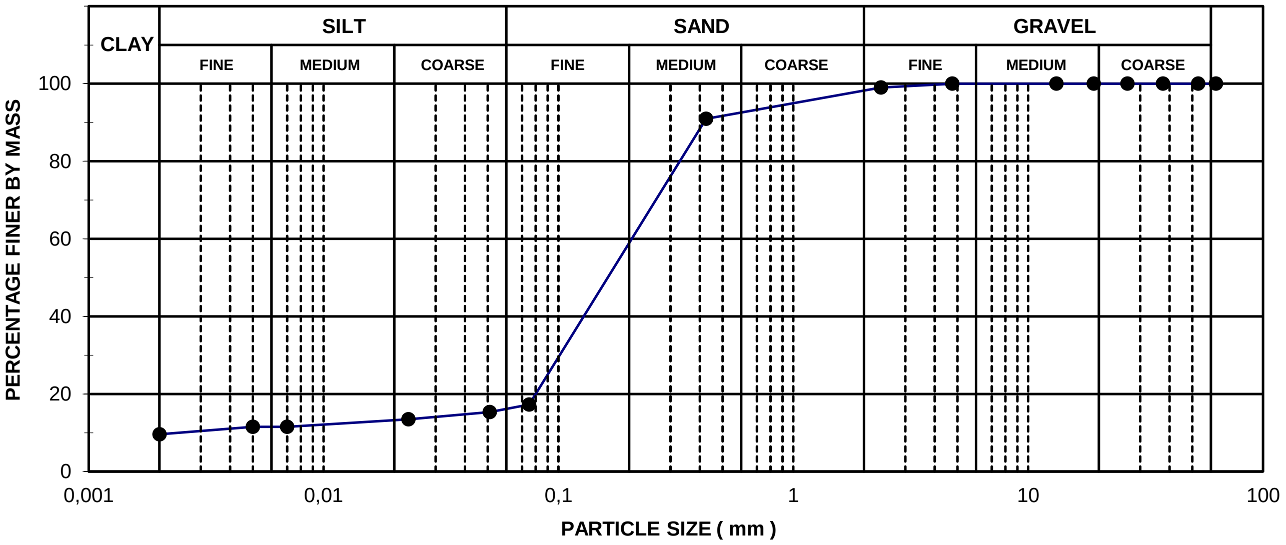
TEST LOCATION	EB TP 11	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13950	PROJECT NUMBER	113834
DEPTH	0,0-1,1 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS			
Sieve (mm)	% Passing	Sieve (mm)	% Passing
63,000	**100**	0,425	**91**
53,000	**100**	0,075	**17**
37,500	**100**	0,051	**15**
26,500	**100**	0,023	**13**
19,000	**100**	0,007	**12**
13,200	**100**	0,002	**10**
4,750	**100**	0,000	**0**
2,360	**99**	0,000	**0**

ATTERBERG LIMITS		
Liquid limit	(%)	**0,0**
Plastic limit	(%)	**0**
Plasticity Index	(%)	**0**
Weighted PI	(%)	**0**
Linear Shrinkage	(%)	**0,0**
Grading Modulus		**0,93**
Uniformity coefficient		**106**
Coefficient of curvature		**25,9**

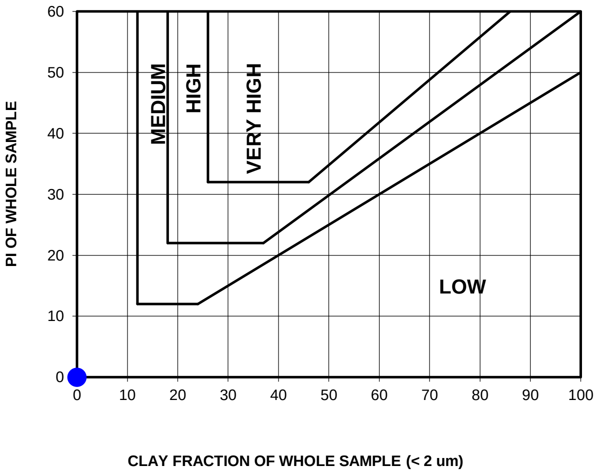
SOIL CLASSIFICATION	
% Gravel	**1**
% Sand	**82**
% Silt	**8**
% Clay	**10**
Activity	**0,0**
Unified Classification	**SM**
TRB Classification	**A - 2 - 4**

PARTICLE SIZE DISTRIBUTION



POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



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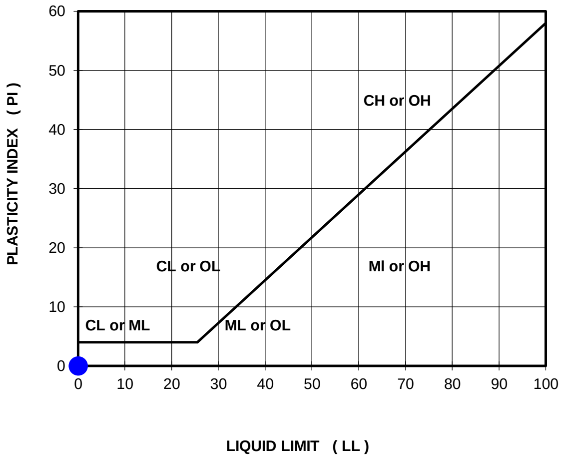
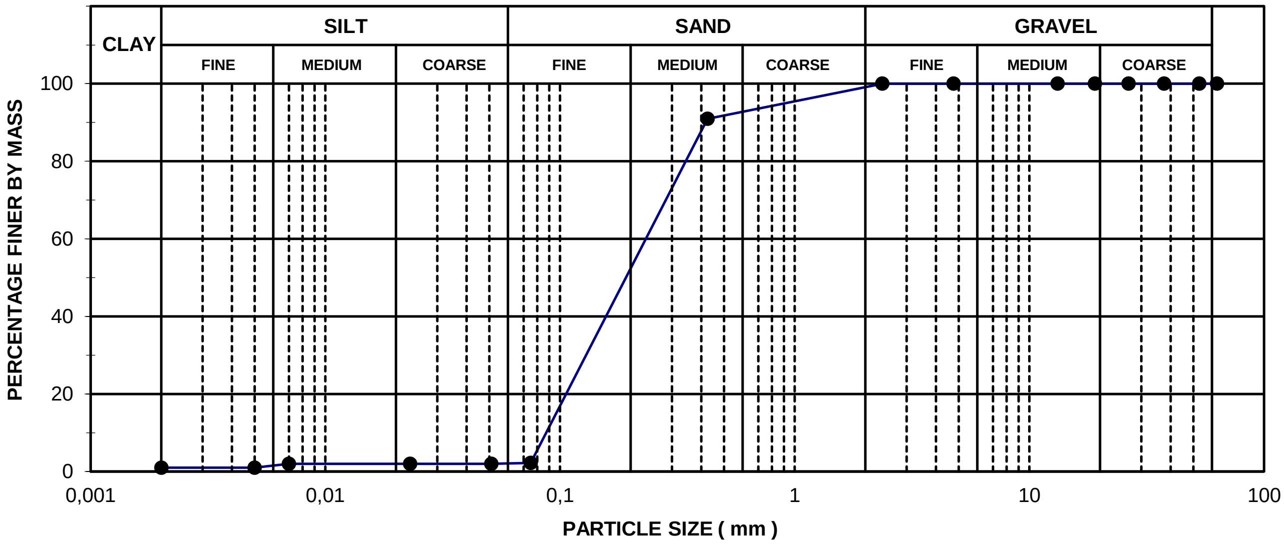


FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	EB TP 14	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13948	PROJECT NUMBER	113834
DEPTH	0,0-1,70 m	SITE	Ebenhaeser Scheme

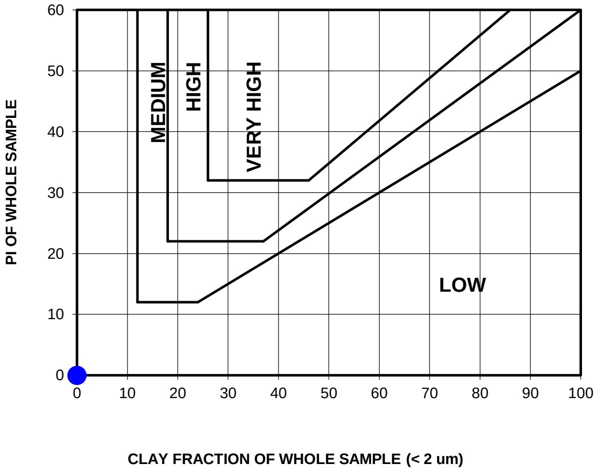
SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**91**	Liquid limit	(%)	**0,0**	% Gravel	**0**
53,000	**100**	0,075	**2**	Plastic limit	(%)	**0**	% Sand	**98**
37,500	**100**	0,051	**2**	Plasticity Index	(%)	**0**	% Silt	**1**
26,500	**100**	0,023	**2**	Weighted PI	(%)	**0**	% Clay	**1**
19,000	**100**	0,007	**2**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**100**	0,002	**1**	Grading Modulus		**1,07**	Unified Classification	
4,750	**100**	0,000	**0**	Uniformity coefficient		**3**	TRB Classification	**A - 3**
2,360	**100**	0,000	**0**	Coefficient of curvature		**1,1**		

PARTICLE SIZE DISTRIBUTION

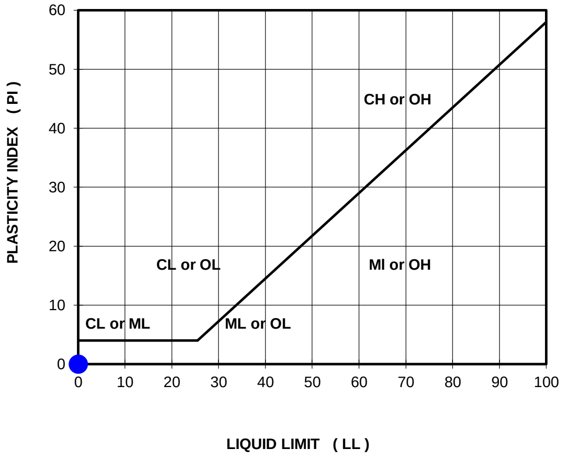


POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE



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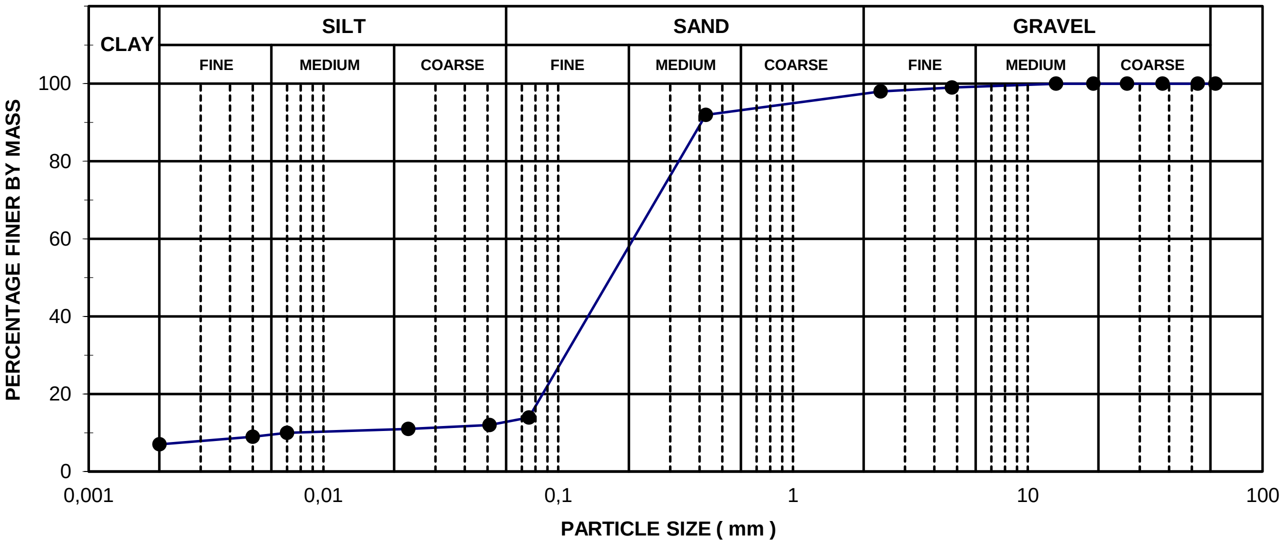
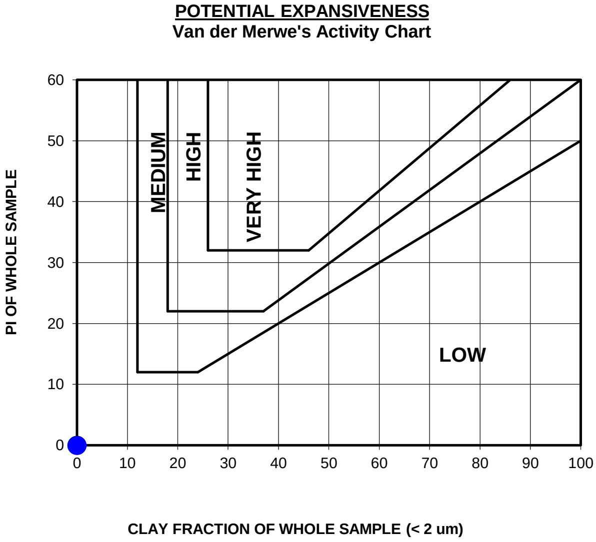
FOUNDATION INDICATOR TEST RESULTS

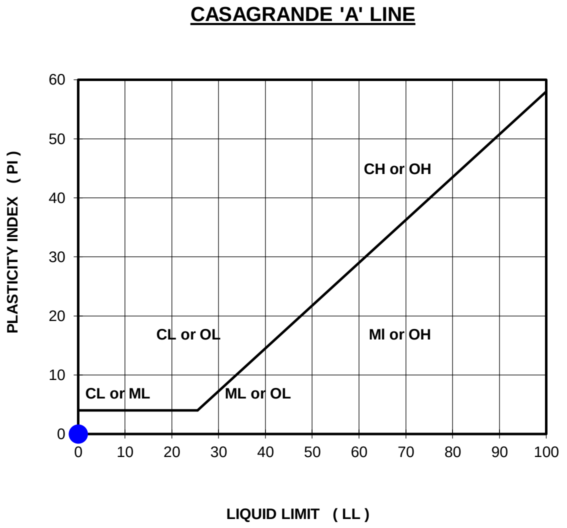
TEST LOCATION	EB TP 15	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13949	PROJECT NUMBER	113834
DEPTH	0,0-1,40 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**92**	Liquid limit	(%)	**0,0**	% Gravel	**2**
53,000	**100**	0,075	**14**	Plastic limit	(%)	**0**	% Sand	**84**
37,500	**100**	0,051	**12**	Plasticity Index	(%)	**0**	% Silt	**7**
26,500	**100**	0,023	**11**	Weighted PI	(%)	**0**	% Clay	**7**
19,000	**100**	0,007	**10**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**100**	0,002	**7**	Grading Modulus		**0,96**	Unified Classification	**SM**
4,750	**99**	0,000	**0**	Uniformity coefficient		**20**	TRB Classification	**A - 2 - 4**
2,360	**98**	0,000	**0**	Coefficient of curvature		**5,6**		

PARTICLE SIZE DISTRIBUTION







FOUNDATION INDICATOR TEST RESULTS

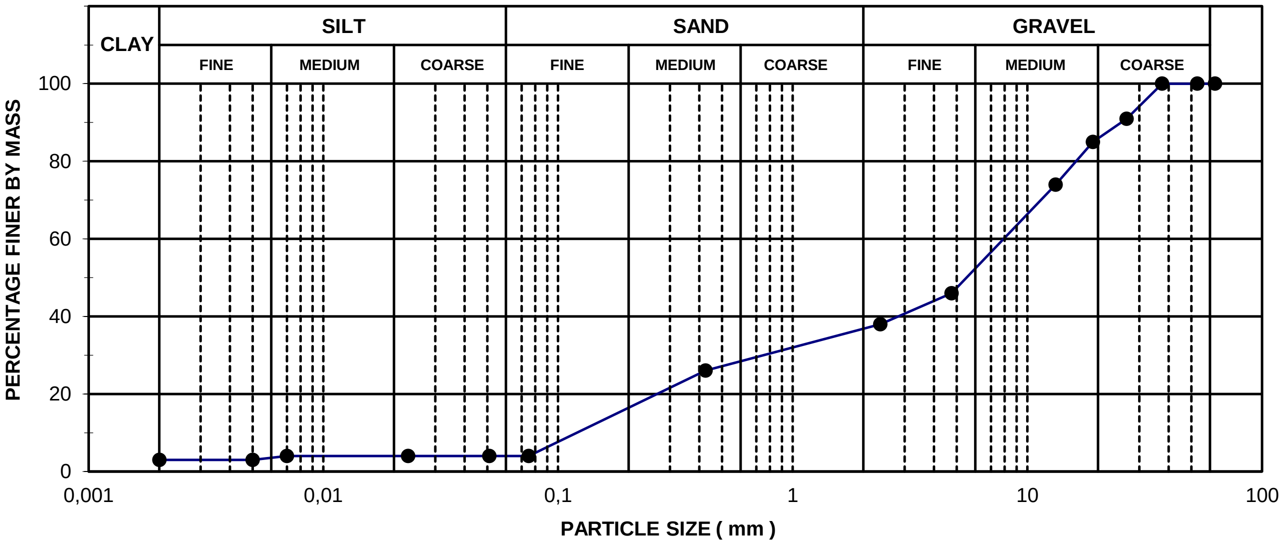
TEST LOCATION	EB TP 16	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13952	PROJECT NUMBER	113834
DEPTH	0,3-0,5 m	SITE	Ebenhaeser Scheme

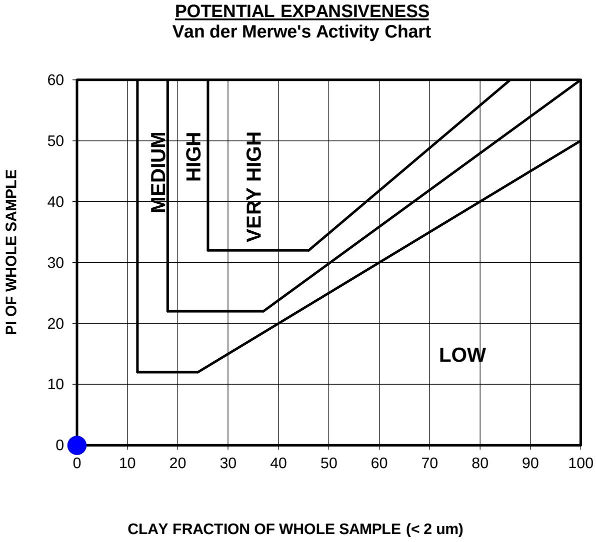
SIEVE ANALYSIS			
Sieve (mm)	% Passing	Sieve (mm)	% Passing
63,000	**100**	0,425	**26**
53,000	**100**	0,075	**4**
37,500	**100**	0,051	**4**
26,500	**91**	0,023	**4**
19,000	**85**	0,007	**4**
13,200	**74**	0,002	**3**
4,750	**46**	0,000	**0**
2,360	**38**	0,000	**0**

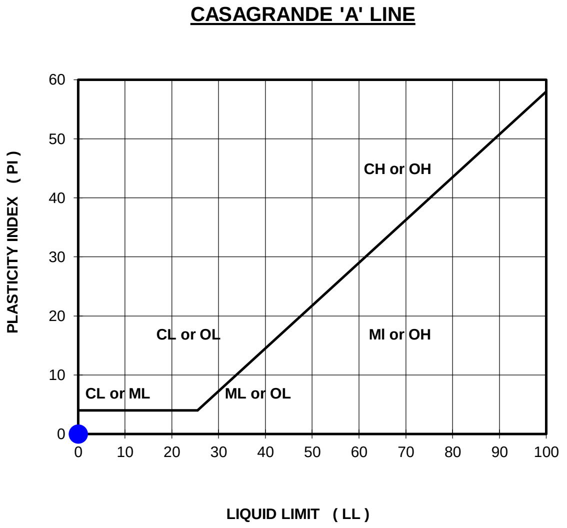
ATTERBERG LIMITS		
Liquid limit	(%)	**0,0**
Plastic limit	(%)	**0**
Plasticity Index	(%)	**0**
Weighted PI	(%)	**0**
Linear Shrinkage	(%)	**0,0**
Grading Modulus		**2,32**
Uniformity coefficient		**52**
Coefficient of curvature		**0,7**

SOIL CLASSIFICATION	
% Gravel	**62**
% Sand	**34**
% Silt	**1**
% Clay	**3**
Activity	**0,0**
Unified Classification	**GP**
TRB Classification	**A - 1 - a**

PARTICLE SIZE DISTRIBUTION







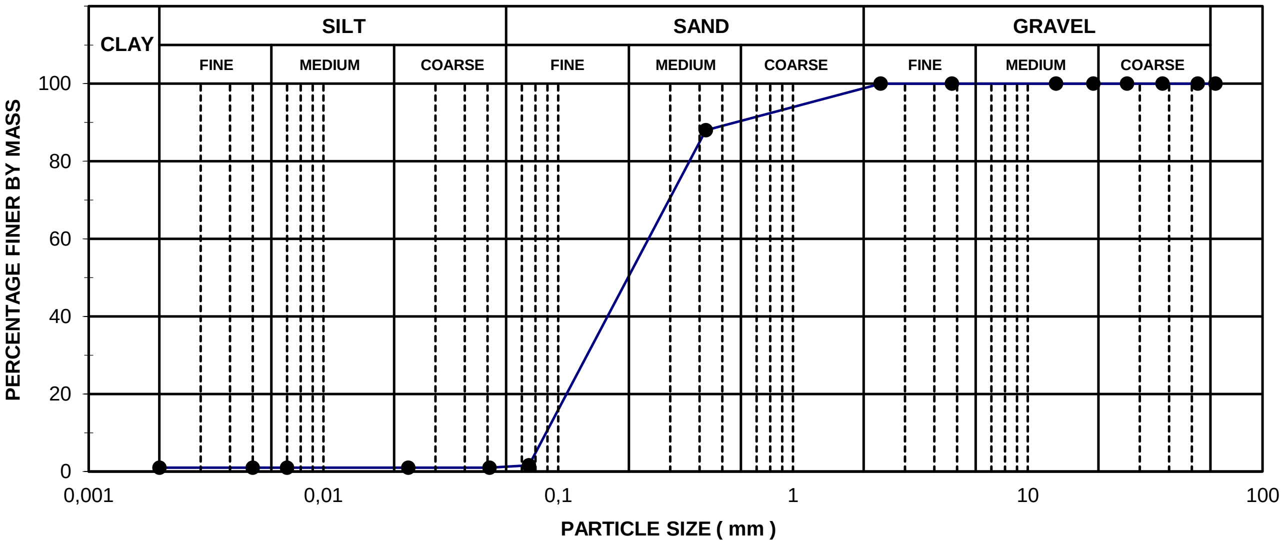
aurecon

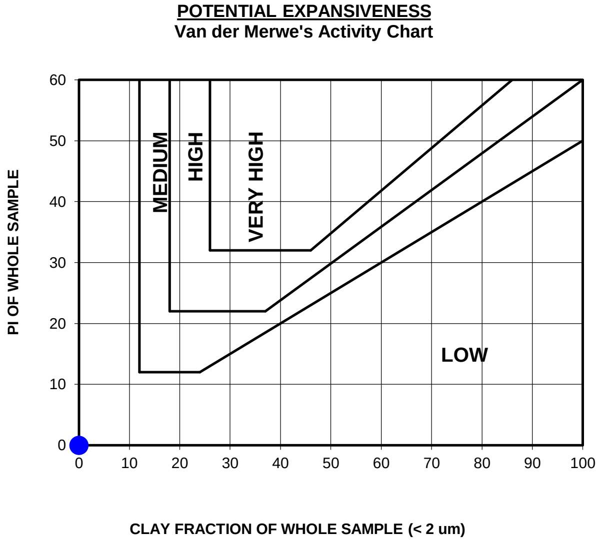
FOUNDATION INDICATOR TEST RESULTS

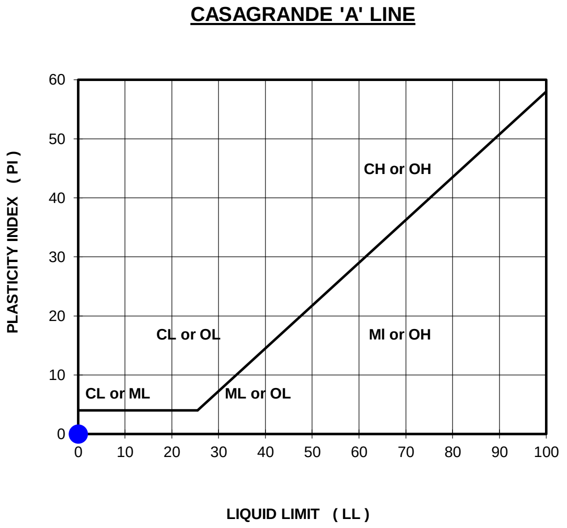
TEST LOCATION	EB TP 17	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13907	PROJECT NUMBER	113834
DEPTH	0.0-1.7 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**88**	Liquid limit	(%)	**0,0**	% Gravel	**0**
53,000	**100**	0,075	**2**	Plastic limit	(%)	**0**	% Sand	**98**
37,500	**100**	0,051	**1**	Plasticity Index	(%)	**0**	% Silt	**1**
26,500	**100**	0,023	**1**	Weighted PI	(%)	**0**	% Clay	**1**
19,000	**100**	0,007	**1**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**100**	0,002	**1**	Grading Modulus		**1,10**	Unified Classification	
4,750	**100**	0,000	**0**	Uniformity coefficient		**3**	TRB Classification	**A - 3**
2,360	**100**	0,000	**0**	Coefficient of curvature		**1,1**		

PARTICLE SIZE DISTRIBUTION





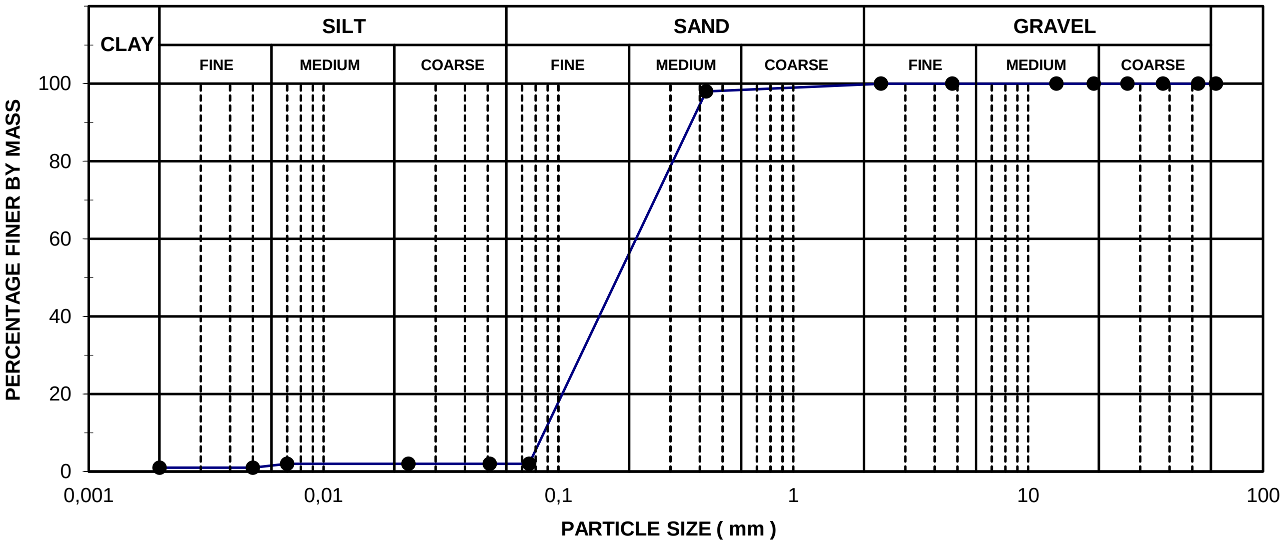


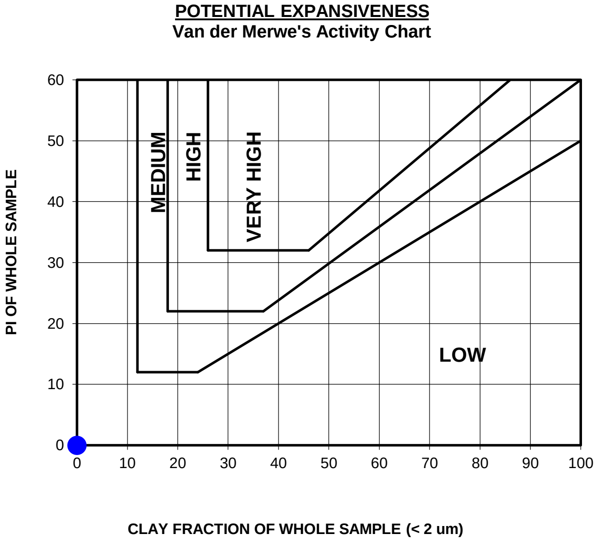
FOUNDATION INDICATOR TEST RESULTS

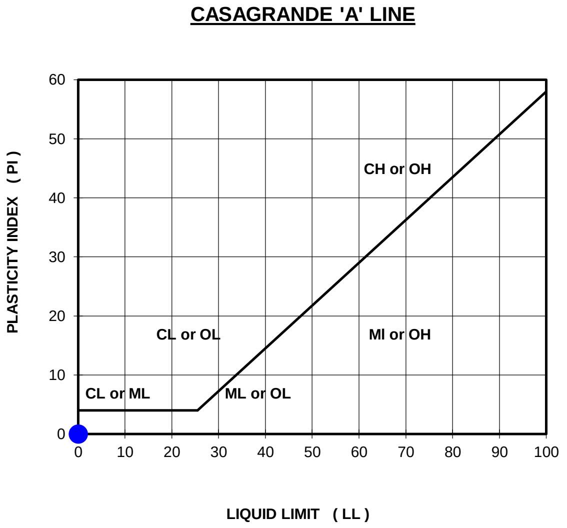
TEST LOCATION	EB TP 18	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13954	PROJECT NUMBER	113834
DEPTH	0,0-2,0 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**98**	Liquid limit	(%)	**0,0**	% Gravel	**0**
53,000	**100**	0,075	**2**	Plastic limit	(%)	**0**	% Sand	**98**
37,500	**100**	0,051	**2**	Plasticity Index	(%)	**0**	% Silt	**1**
26,500	**100**	0,023	**2**	Weighted PI	(%)	**0**	% Clay	**1**
19,000	**100**	0,007	**2**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**100**	0,002	**1**	Grading Modulus		**1,00**	Unified Classification	
4,750	**100**	0,000	**0**	Uniformity coefficient		**3**	TRB Classification	**A - 3**
2,360	**100**	0,000	**0**	Coefficient of curvature		**1,1**		

PARTICLE SIZE DISTRIBUTION







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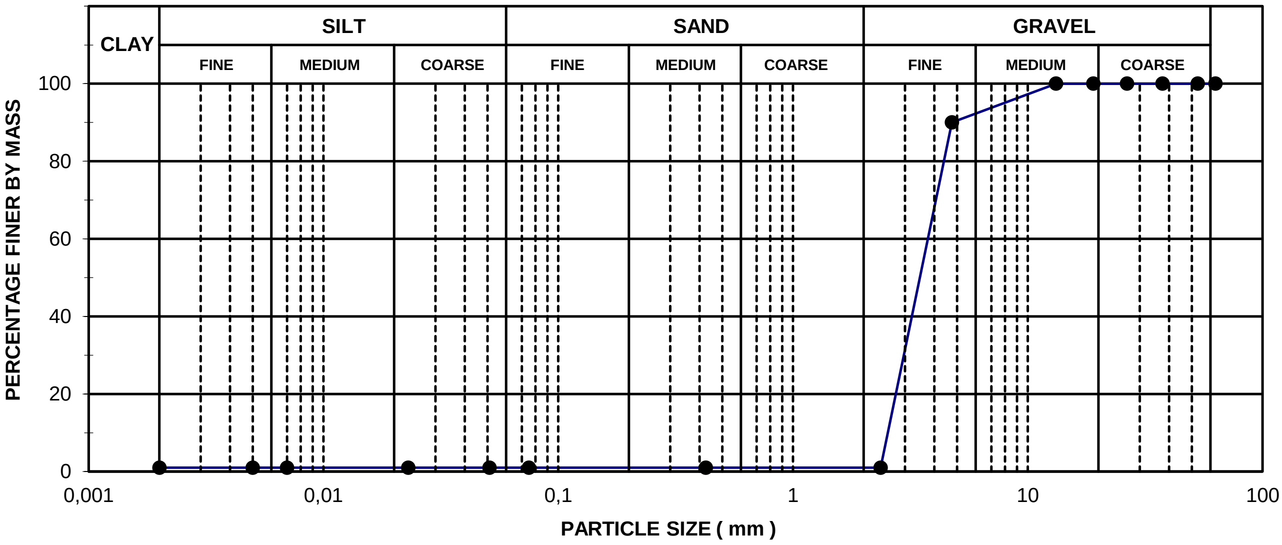
FOUNDATION INDICATOR TEST RESULTS

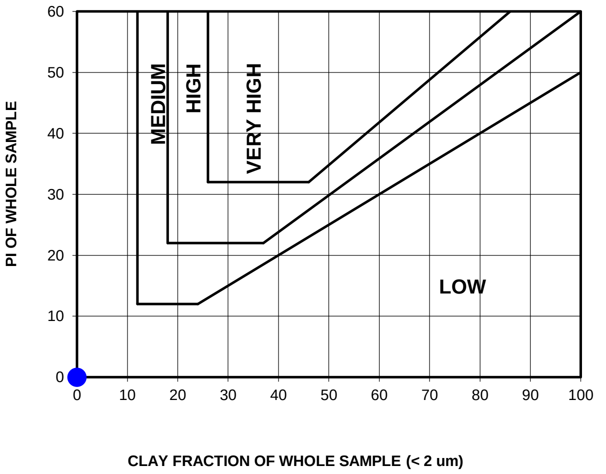
TEST LOCATION	EB TP 24ADD	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13946	PROJECT NUMBER	113834
DEPTH	0,0-2,20 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**1**	Liquid limit	(%)	**0,0**	% Gravel	**99**
53,000	**100**	0,075	**1**	Plastic limit	(%)	**0**	% Sand	**0**
37,500	**100**	0,051	**1**	Plasticity Index	(%)	**0**	% Silt	**0**
26,500	**100**	0,023	**1**	Weighted PI	(%)	**0**	% Clay	**1**
19,000	**100**	0,007	**1**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**100**	0,002	**1**	Grading Modulus		**2,97**	Unified Classification	**GP**
4,750	**90**	0,000	**0**	Uniformity coefficient		**2**	TRB Classification	**A - 1 - a**
2,360	**1**	0,000	**0**	Coefficient of curvature		**1,0**		

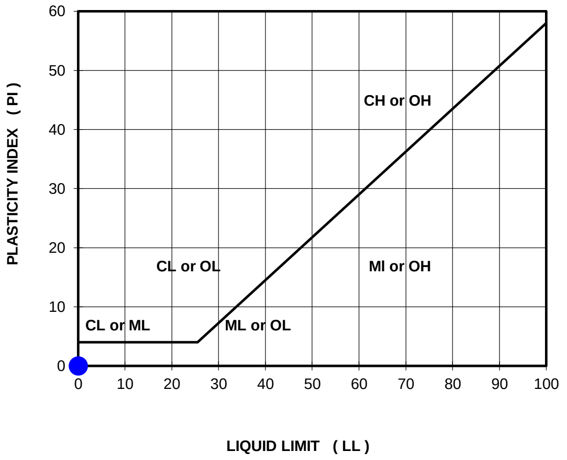
PARTICLE SIZE DISTRIBUTION



POTENTIAL EXPANSIVENESS
Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE

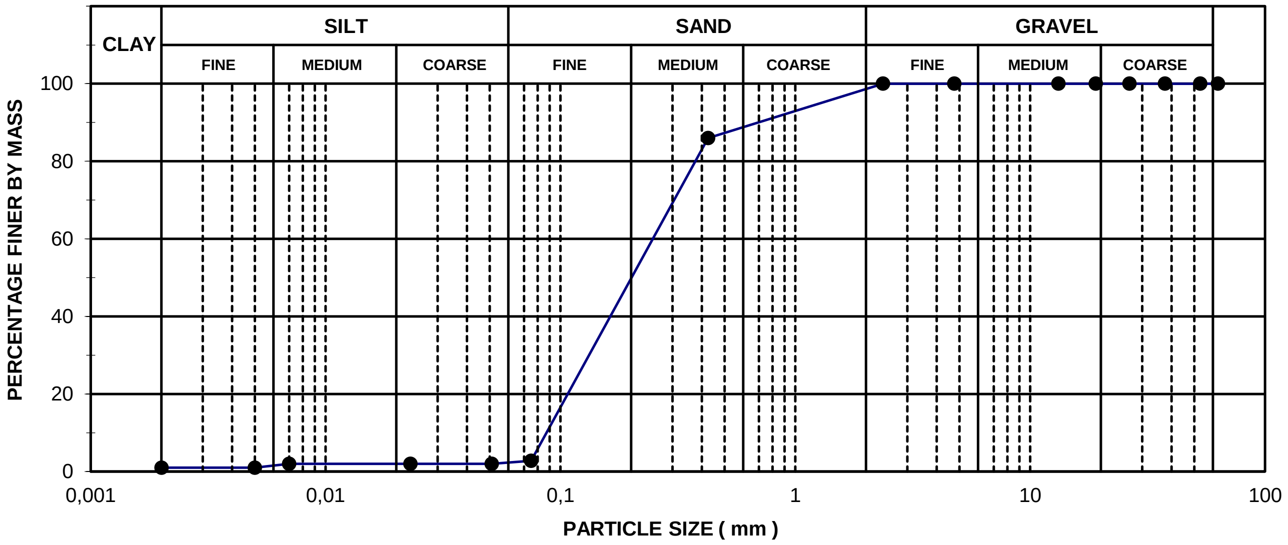


FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	EB TP 28	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13938	PROJECT NUMBER	113834
DEPTH	0,0-2,5 m	SITE	Ebenhaeser Scheme

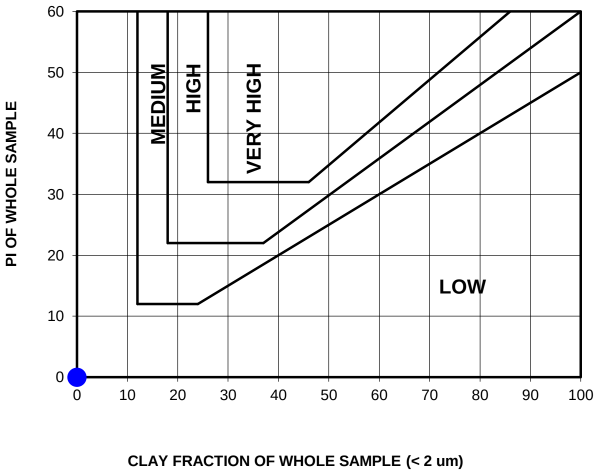
SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**86**	Liquid limit	(%)	**0,0**	% Gravel	**0**
53,000	**100**	0,075	**3**	Plastic limit	(%)	**0**	% Sand	**97**
37,500	**100**	0,051	**2**	Plasticity Index	(%)	**0**	% Silt	**2**
26,500	**100**	0,023	**2**	Weighted PI	(%)	**0**	% Clay	**1**
19,000	**100**	0,007	**2**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**100**	0,002	**1**	Grading Modulus		**1,11**	Unified Classification	
4,750	**100**	0,000	**0**	Uniformity coefficient		**3**	TRB Classification	**A - 3**
2,360	**100**	0,000	**0**	Coefficient of curvature		**1,1**		

PARTICLE SIZE DISTRIBUTION

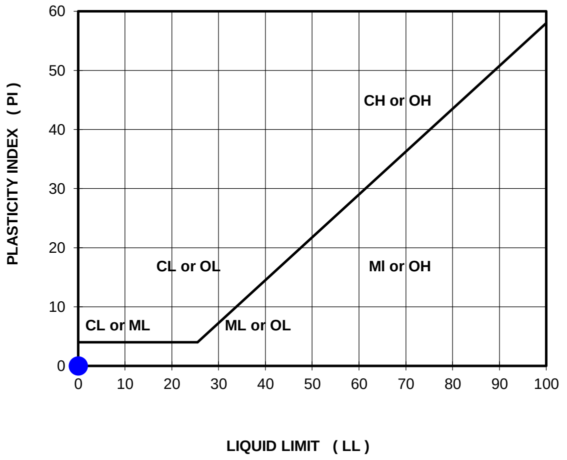


POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE

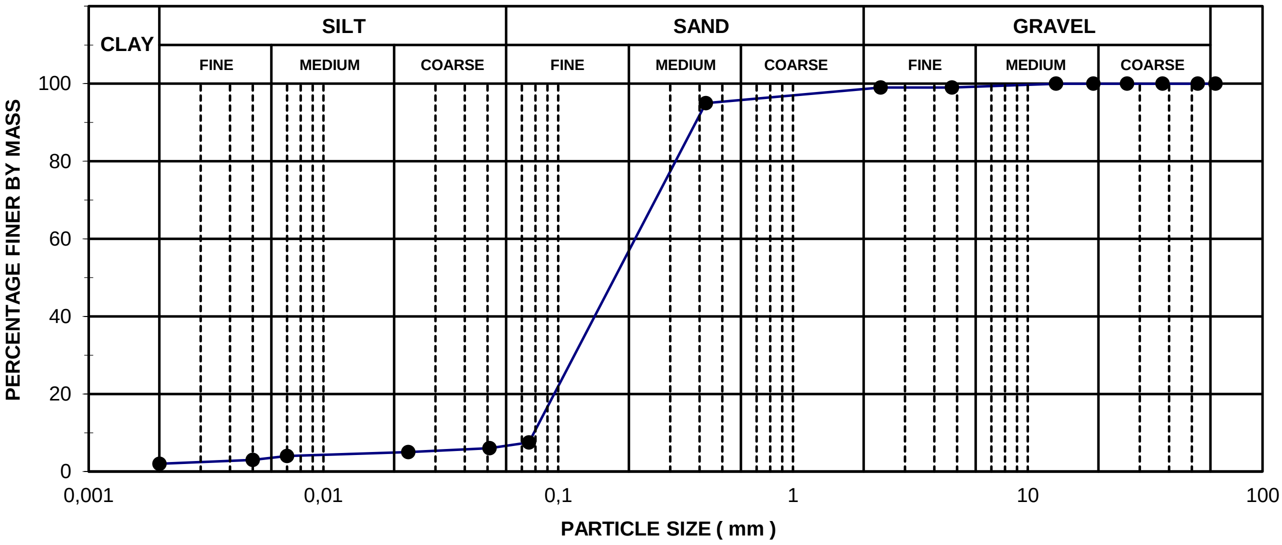


FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	EB TP 33	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13942	PROJECT NUMBER	113834
DEPTH	0,0-1,60 m	SITE	Ebenhaeser Scheme

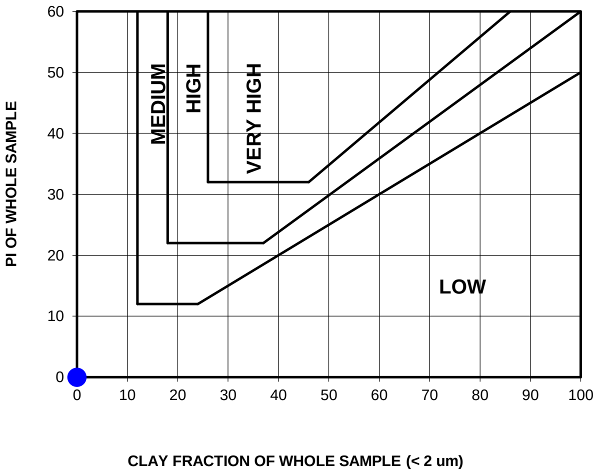
SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**95**	Liquid limit	(%)	**0,0**	% Gravel	**1**
53,000	**100**	0,075	**8**	Plastic limit	(%)	**0**	% Sand	**92**
37,500	**100**	0,051	**6**	Plasticity Index	(%)	**0**	% Silt	**6**
26,500	**100**	0,023	**5**	Weighted PI	(%)	**0**	% Clay	**2**
19,000	**100**	0,007	**4**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**100**	0,002	**2**	Grading Modulus		**0,99**	Unified Classification	**SP-SM**
4,750	**99**	0,000	**0**	Uniformity coefficient		**3**	TRB Classification	**A - 3**
2,360	**99**	0,000	**0**	Coefficient of curvature		**1,1**		

PARTICLE SIZE DISTRIBUTION

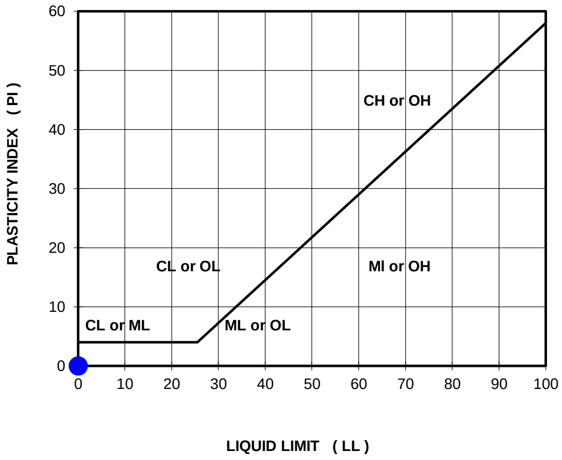


POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE

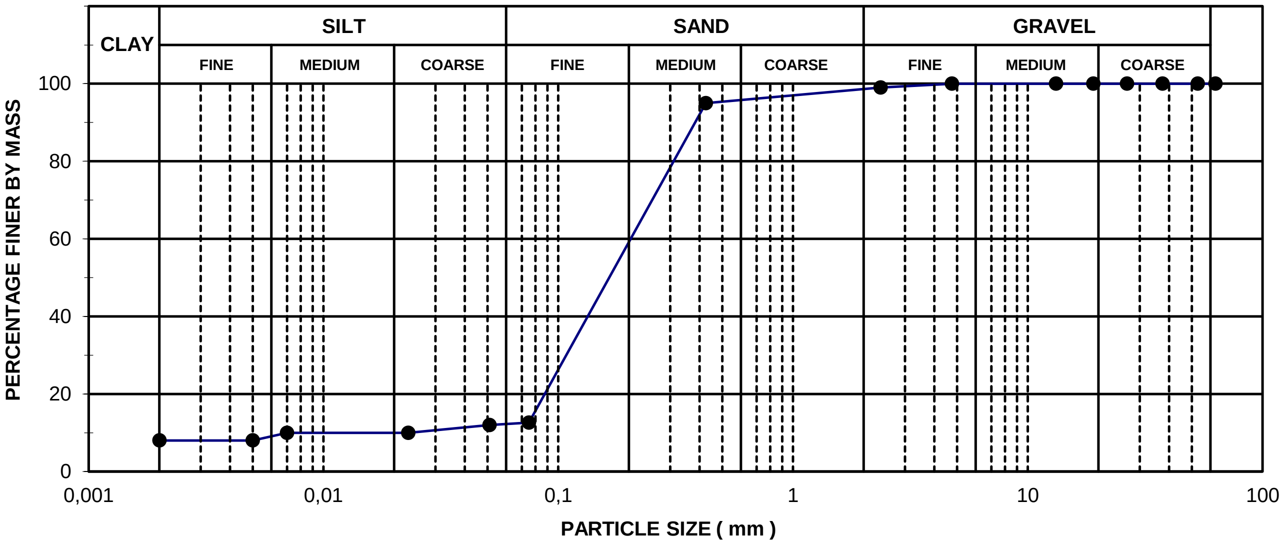


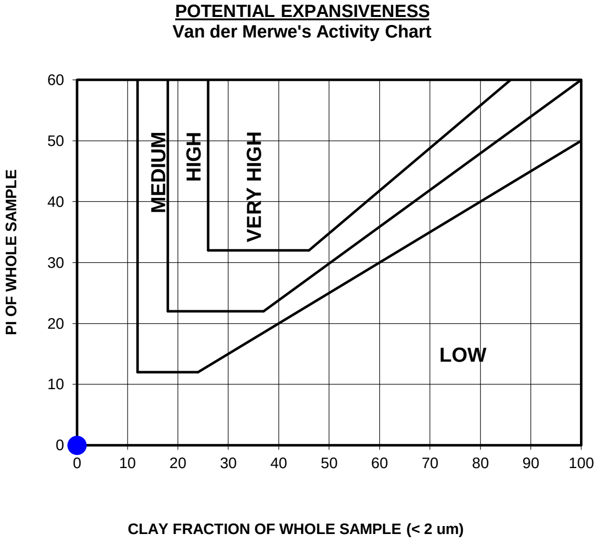
FOUNDATION INDICATOR TEST RESULTS

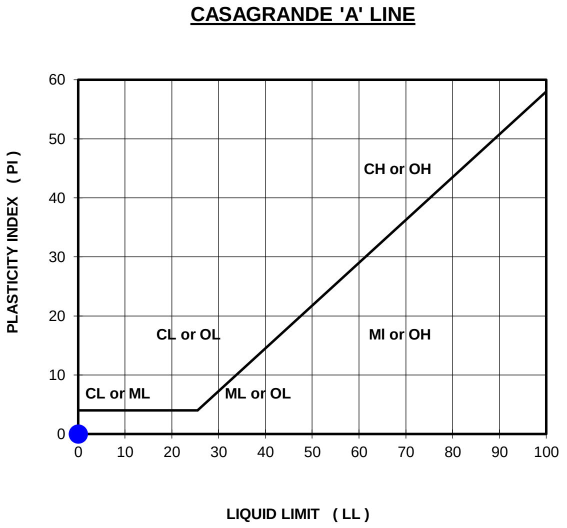
TEST LOCATION	EB TP 33	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13943	PROJECT NUMBER	113834
DEPTH	1,3-1,6 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**95**	Liquid limit	(%)	**0,0**	% Gravel	**1**
53,000	**100**	0,075	**13**	Plastic limit	(%)	**0**	% Sand	**86**
37,500	**100**	0,051	**12**	Plasticity Index	(%)	**0**	% Silt	**5**
26,500	**100**	0,023	**10**	Weighted PI	(%)	**0**	% Clay	**8**
19,000	**100**	0,007	**10**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**100**	0,002	**8**	Grading Modulus		**0,93**	Unified Classification	**SM**
4,750	**100**	0,000	**0**	Uniformity coefficient		**9**	TRB Classification	**A - 2 - 4**
2,360	**99**	0,000	**0**	Coefficient of curvature		**2,7**		

PARTICLE SIZE DISTRIBUTION





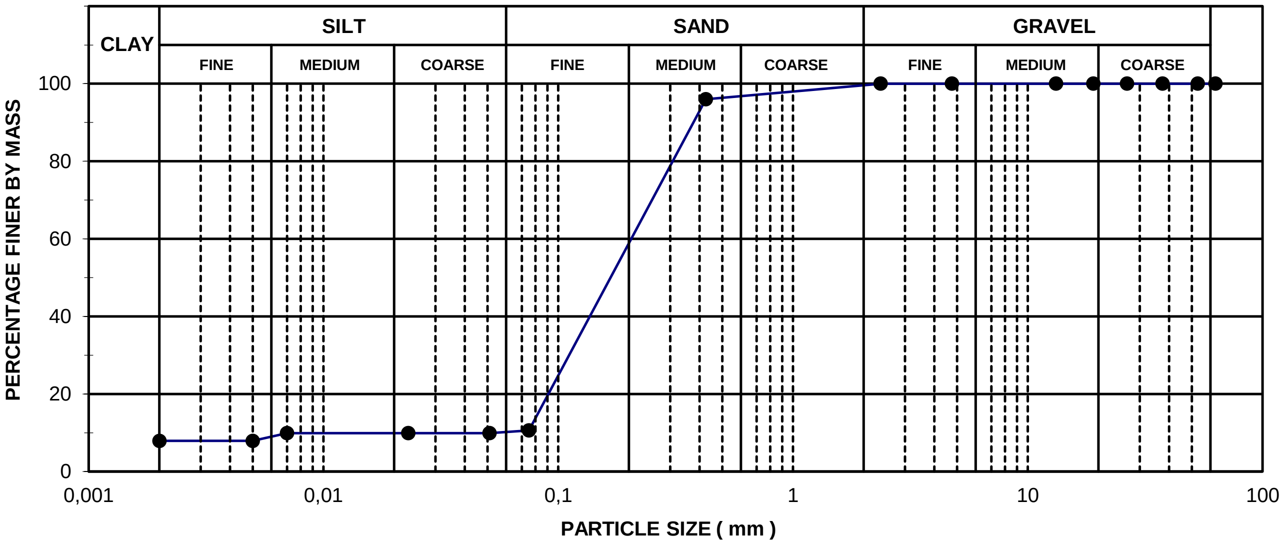


FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	EB TP 35	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13939	PROJECT NUMBER	113834
DEPTH	1,20-1,50 m	SITE	Ebenhaeser Scheme

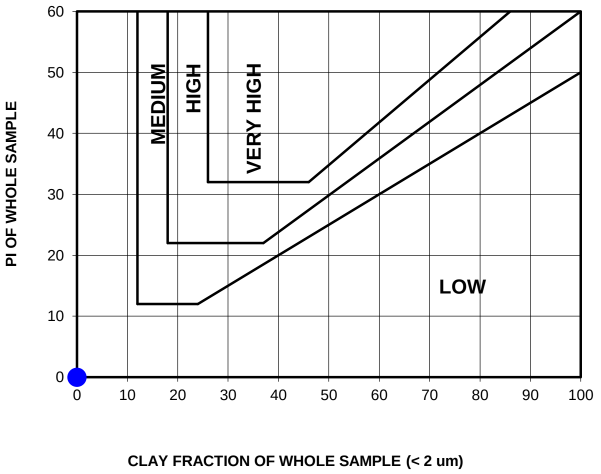
SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**96**	Liquid limit	(%)	**0,0**	% Gravel	**0**
53,000	**100**	0,075	**11**	Plastic limit	(%)	**0**	% Sand	**89**
37,500	**100**	0,051	**10**	Plasticity Index	(%)	**0**	% Silt	**3**
26,500	**100**	0,023	**10**	Weighted PI	(%)	**0**	% Clay	**8**
19,000	**100**	0,007	**10**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**100**	0,002	**8**	Grading Modulus		**0,93**	Unified Classification	**SP-SM**
4,750	**100**	0,000	**0**	Uniformity coefficient		**5**	TRB Classification	**A - 2 - 4**
2,360	**100**	0,000	**0**	Coefficient of curvature		**1,6**		

PARTICLE SIZE DISTRIBUTION

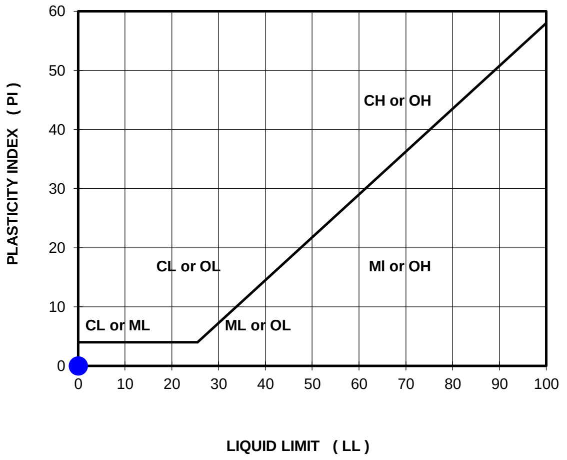


POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE

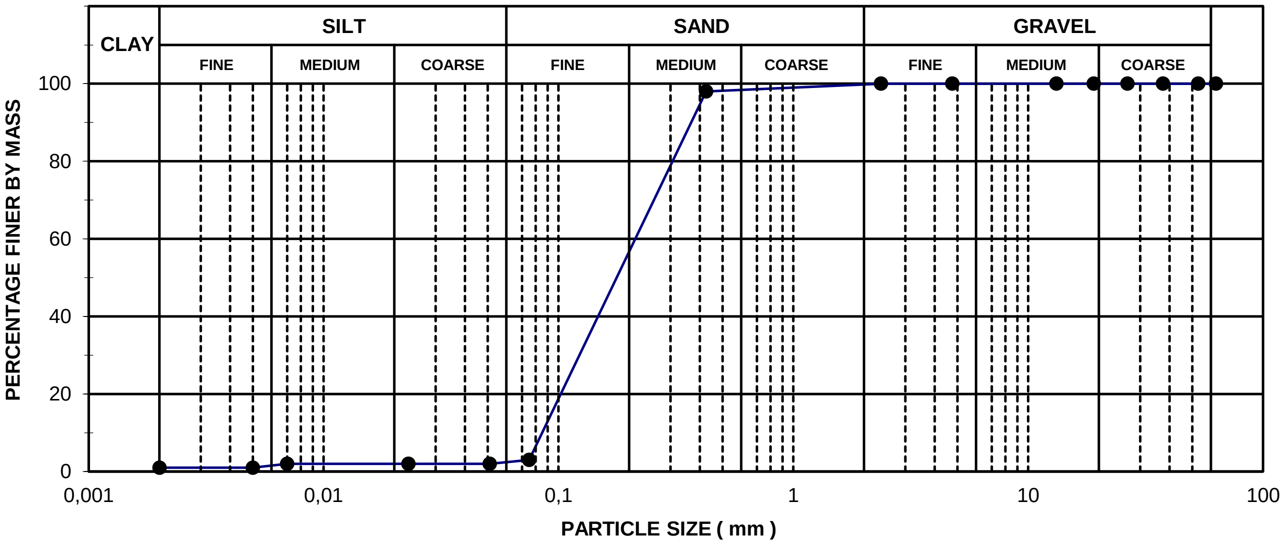


FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	EB TP 38	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13940	PROJECT NUMBER	113834
DEPTH	0,0-0,90 m	SITE	Ebenhaeser Scheme

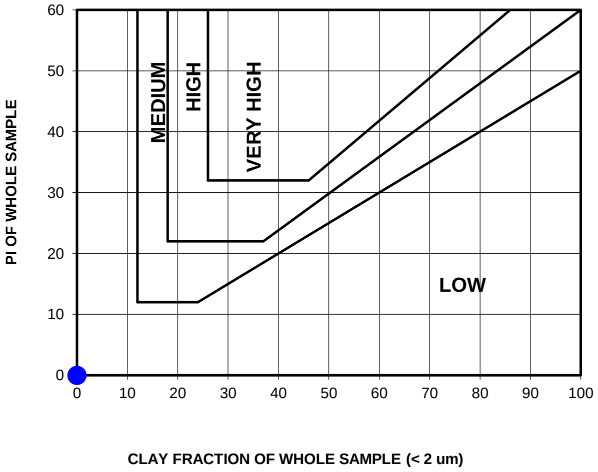
SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**98**	Liquid limit	(%)	**0,0**	% Gravel	**0**
53,000	**100**	0,075	**3**	Plastic limit	(%)	**0**	% Sand	**97**
37,500	**100**	0,051	**2**	Plasticity Index	(%)	**0**	% Silt	**2**
26,500	**100**	0,023	**2**	Weighted PI	(%)	**0**	% Clay	**1**
19,000	**100**	0,007	**2**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**100**	0,002	**1**	Grading Modulus		**0,99**	Unified Classification	
4,750	**100**	0,000	**0**	Uniformity coefficient		**3**	TRB Classification	**A - 3**
2,360	**100**	0,000	**0**	Coefficient of curvature		**1,1**		

PARTICLE SIZE DISTRIBUTION

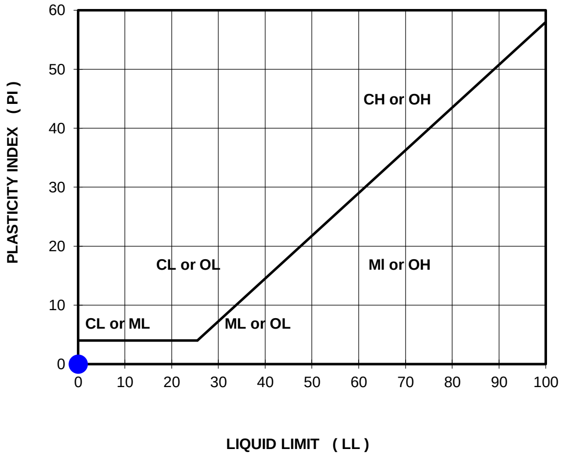


POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE

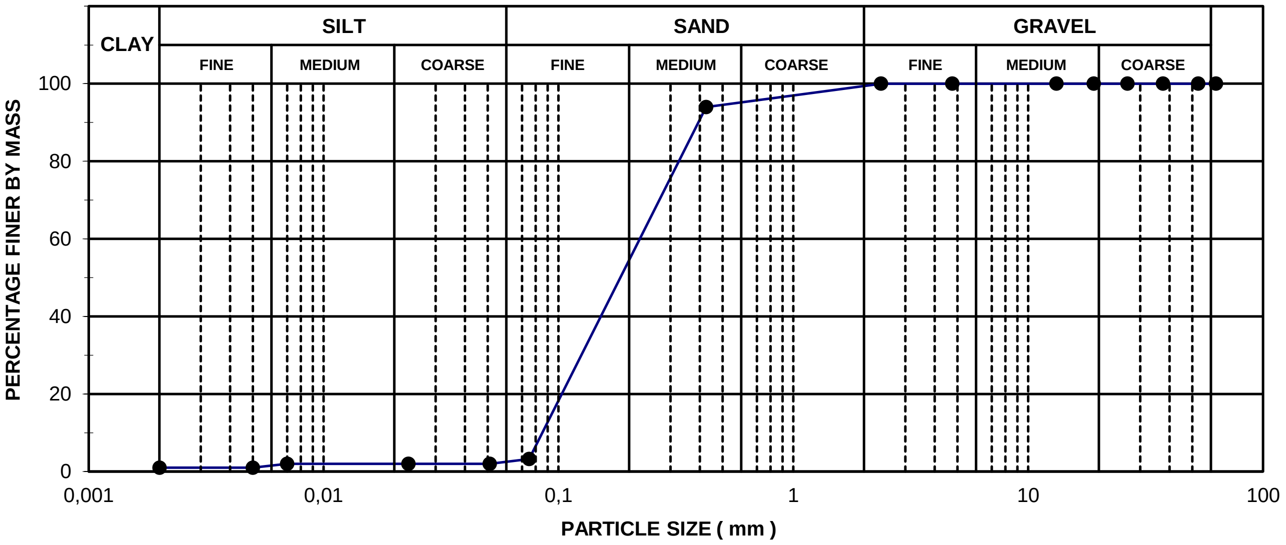


FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	EB TP 40	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13955	PROJECT NUMBER	113834
DEPTH	1,1-2,50 m	SITE	Ebenhaeser Scheme

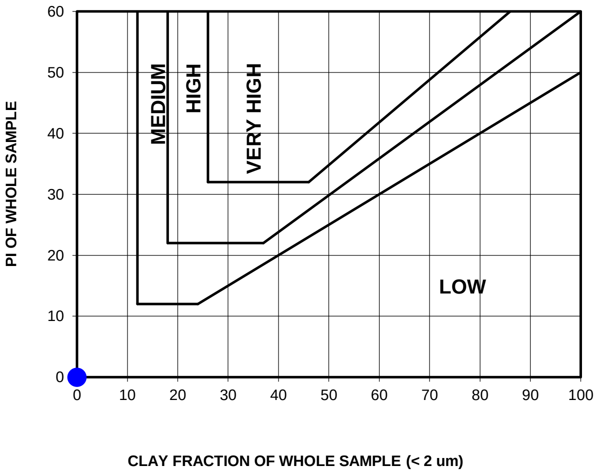
SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**94**	Liquid limit	(%)	**0,0**	% Gravel	**0**
53,000	**100**	0,075	**3**	Plastic limit	(%)	**0**	% Sand	**97**
37,500	**100**	0,051	**2**	Plasticity Index	(%)	**0**	% Silt	**2**
26,500	**100**	0,023	**2**	Weighted PI	(%)	**0**	% Clay	**1**
19,000	**100**	0,007	**2**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**100**	0,002	**1**	Grading Modulus		**1,03**	Unified Classification	
4,750	**100**	0,000	**0**	Uniformity coefficient		**3**	TRB Classification	**A - 3**
2,360	**100**	0,000	**0**	Coefficient of curvature		**1,1**		

PARTICLE SIZE DISTRIBUTION

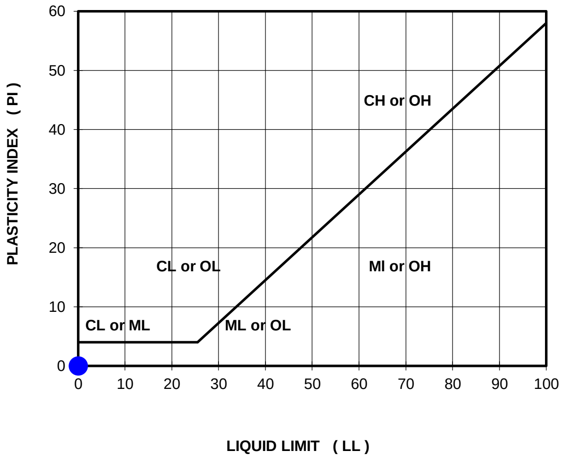


POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE



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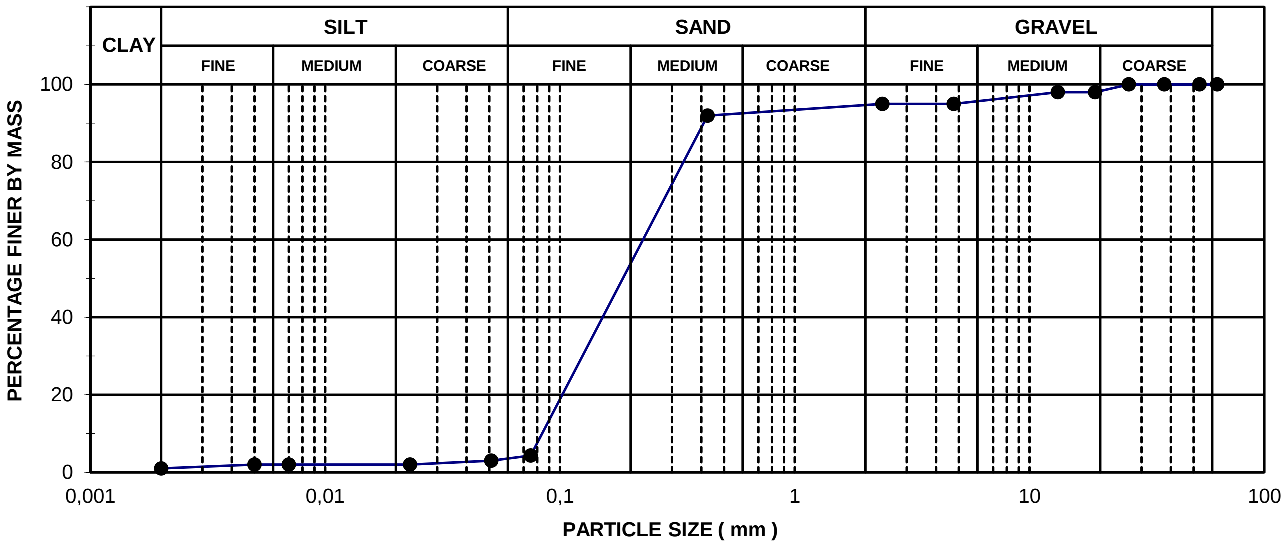
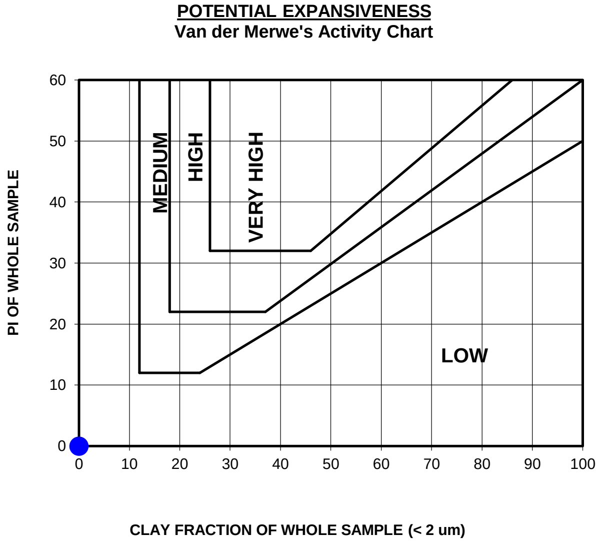
FOUNDATION INDICATOR TEST RESULTS

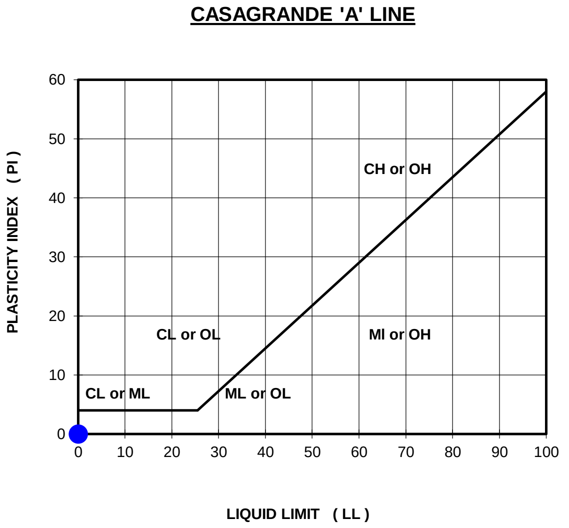
TEST LOCATION	EB TP41	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13941	PROJECT NUMBER	113834
DEPTH	0,0-0,80 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**92**	Liquid limit	(%)	**0,0**	% Gravel	**5**
53,000	**100**	0,075	**4**	Plastic limit	(%)	**0**	% Sand	**91**
37,500	**100**	0,051	**3**	Plasticity Index	(%)	**0**	% Silt	**3**
26,500	**100**	0,023	**2**	Weighted PI	(%)	**0**	% Clay	**1**
19,000	**98**	0,007	**2**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**98**	0,002	**1**	Grading Modulus		**1,09**	Unified Classification	
4,750	**95**	0,000	**0**	Uniformity coefficient		**3**	TRB Classification	**A - 3**
2,360	**95**	0,000	**0**	Coefficient of curvature		**1,1**		

PARTICLE SIZE DISTRIBUTION





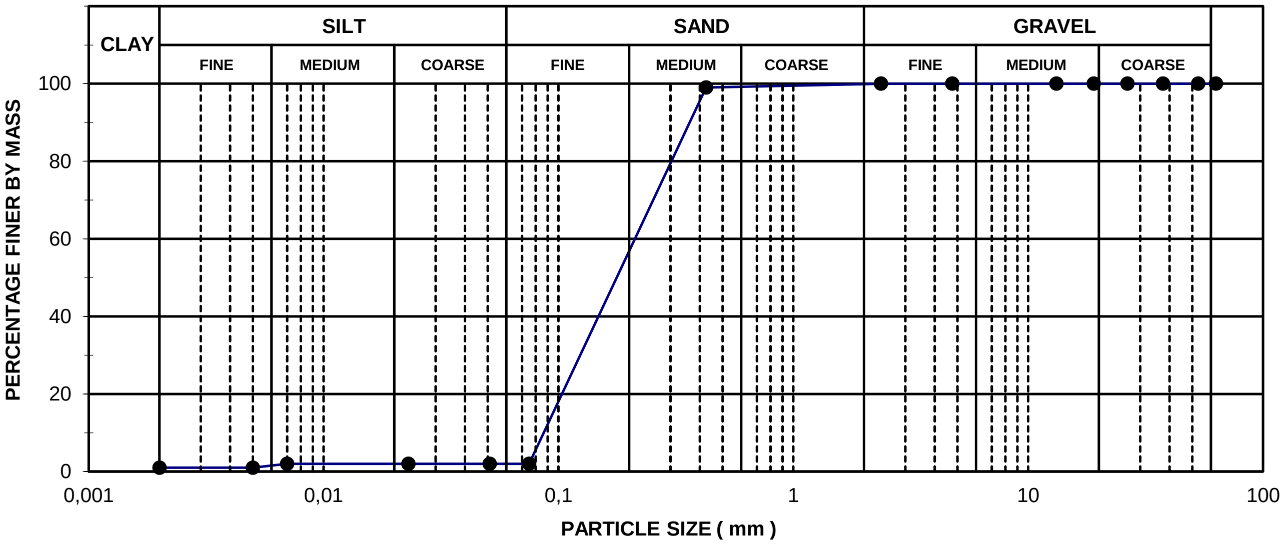


FOUNDATION INDICATOR TEST RESULTS

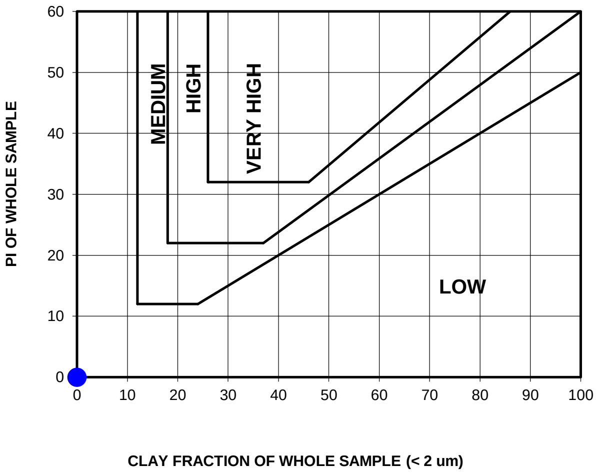
TEST LOCATION	EB TP 43	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13924	PROJECT NUMBER	113834
DEPTH	0,0-1,1 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**99**	Liquid limit	(%)	**0,0**	% Gravel	**0**
53,000	**100**	0,075	**2**	Plastic limit	(%)	**0**	% Sand	**98**
37,500	**100**	0,051	**2**	Plasticity Index	(%)	**0**	% Silt	**1**
26,500	**100**	0,023	**2**	Weighted PI	(%)	**0**	% Clay	**1**
19,000	**100**	0,007	**2**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**100**	0,002	**1**	Grading Modulus		**0,99**	Unified Classification	
4,750	**100**	0,000	**0**	Uniformity coefficient		**3**	TRB Classification	**A - 3**
2,360	**100**	0,000	**0**	Coefficient of curvature		**1,1**		

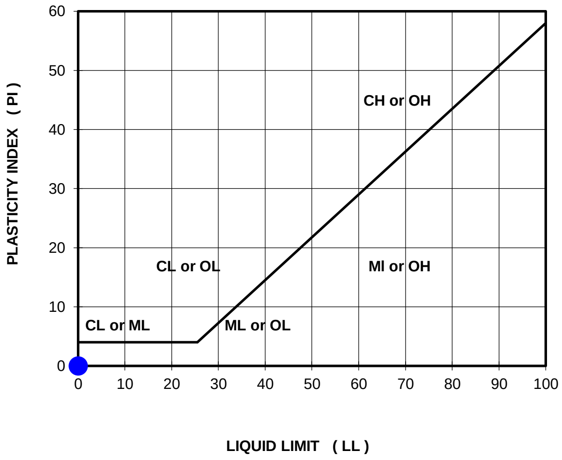
PARTICLE SIZE DISTRIBUTION



POTENTIAL EXPANSIVENESS
Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE

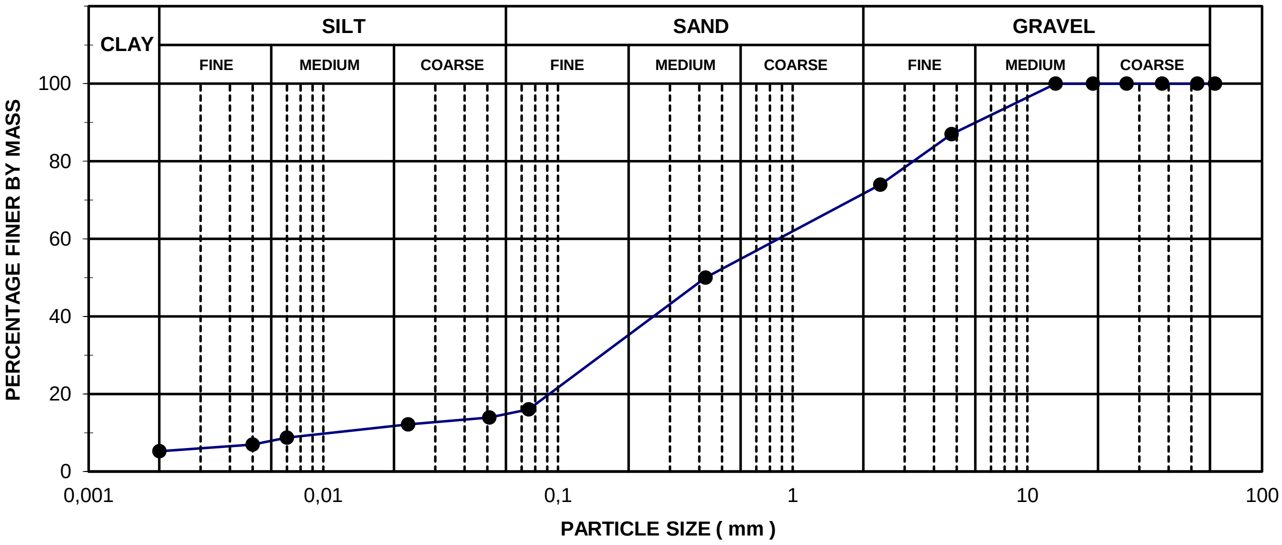


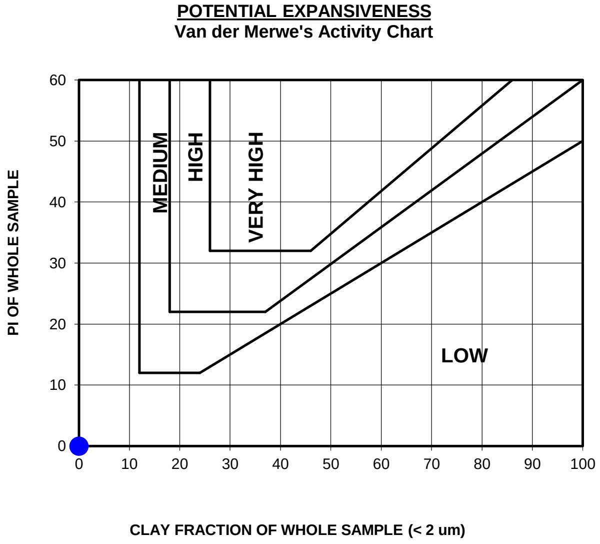
FOUNDATION INDICATOR TEST RESULTS

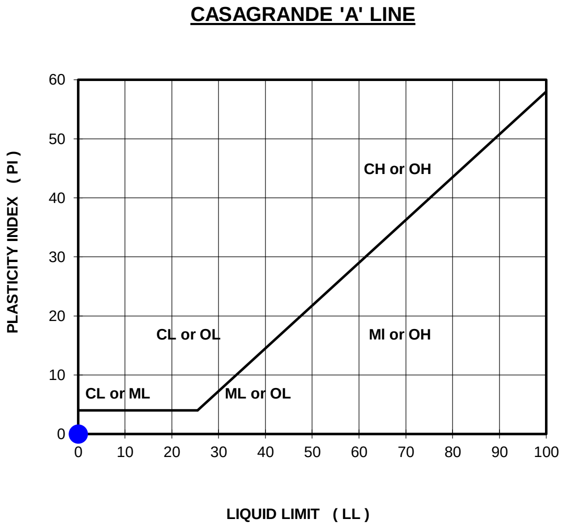
TEST LOCATION	EB TP 45	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13925	PROJECT NUMBER	113834
DEPTH	0.5-1.1 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**50**	Liquid limit	(%)	**0,0**	% Gravel	**26**
53,000	**100**	0,075	**16**	Plastic limit	(%)	**0**	% Sand	**58**
37,500	**100**	0,051	**14**	Plasticity Index	(%)	**0**	% Silt	**11**
26,500	**100**	0,023	**12**	Weighted PI	(%)	**0**	% Clay	**5**
19,000	**100**	0,007	**9**	Linear Shrinkage	(%)	**1,2**	Activity	**0,0**
13,200	**100**	0,002	**5**	Grading Modulus		**1,60**	Unified Classification	**SM**
4,750	**87**	0,000	**0**	Uniformity coefficient		**61**	TRB Classification	**A-- 1 - b**
2,360	**74**	0,000	**0**	Coefficient of curvature		**2,0**		

PARTICLE SIZE DISTRIBUTION







FOUNDATION INDICATOR TEST RESULTS

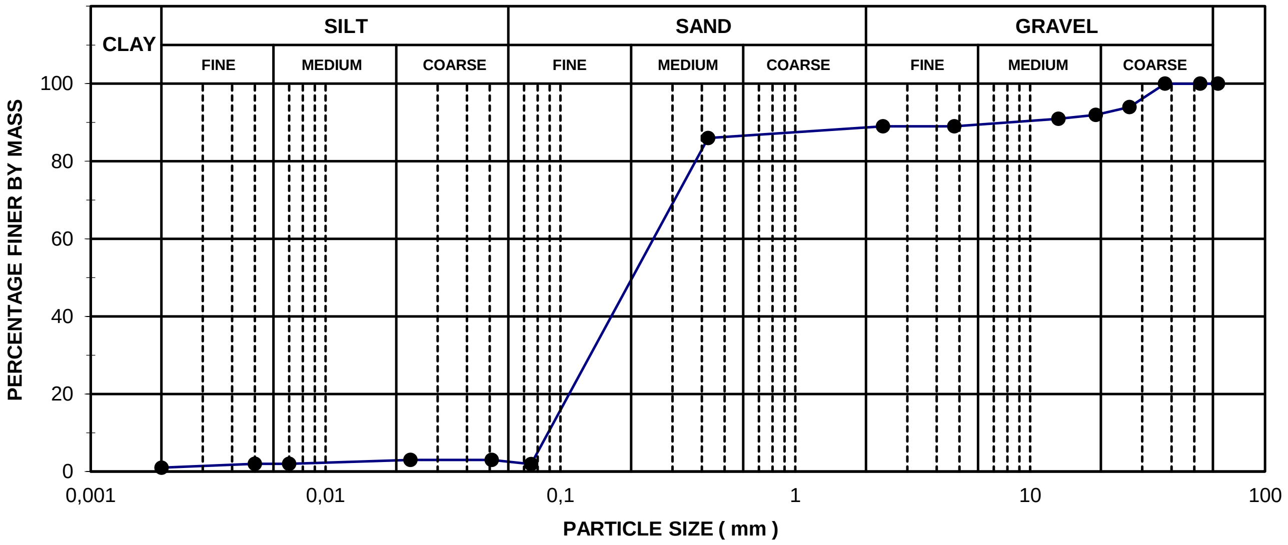
TEST LOCATION	EB TP 46	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13926	PROJECT NUMBER	113834
DEPTH	0,0-0,6 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS			
Sieve (mm)	% Passing	Sieve (mm)	% Passing
63,000	**100**	0,425	**86**
53,000	**100**	0,075	**2**
37,500	**100**	0,051	**3**
26,500	**94**	0,023	**3**
19,000	**92**	0,007	**2**
13,200	**91**	0,002	**1**
4,750	**89**	0,000	**0**
2,360	**89**	0,000	**0**

ATTERBERG LIMITS		
Liquid limit	(%)	**0,0**
Plastic limit	(%)	**0**
Plasticity Index	(%)	**0**
Weighted PI	(%)	**0**
Linear Shrinkage	(%)	**0,0**
Grading Modulus		**1,23**
Uniformity coefficient		**3**
Coefficient of curvature		**1,1**

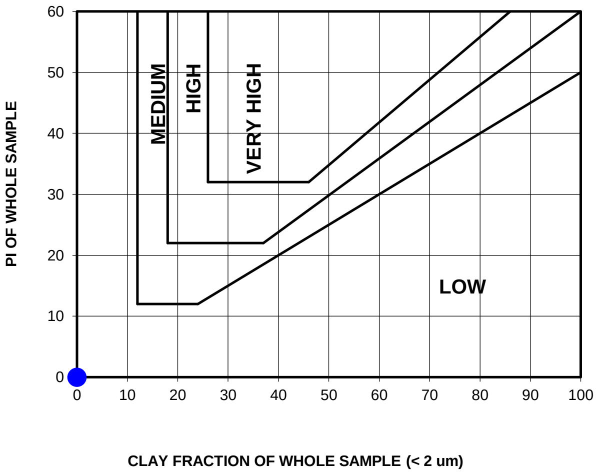
SOIL CLASSIFICATION	
% Gravel	**11**
% Sand	**87**
% Silt	**1**
% Clay	**1**
Activity	**0,0**
Unified Classification	
TRB Classification	**A - 3**

PARTICLE SIZE DISTRIBUTION

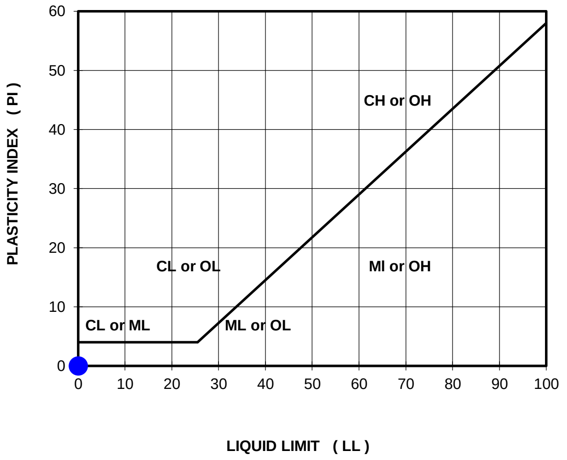


POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE

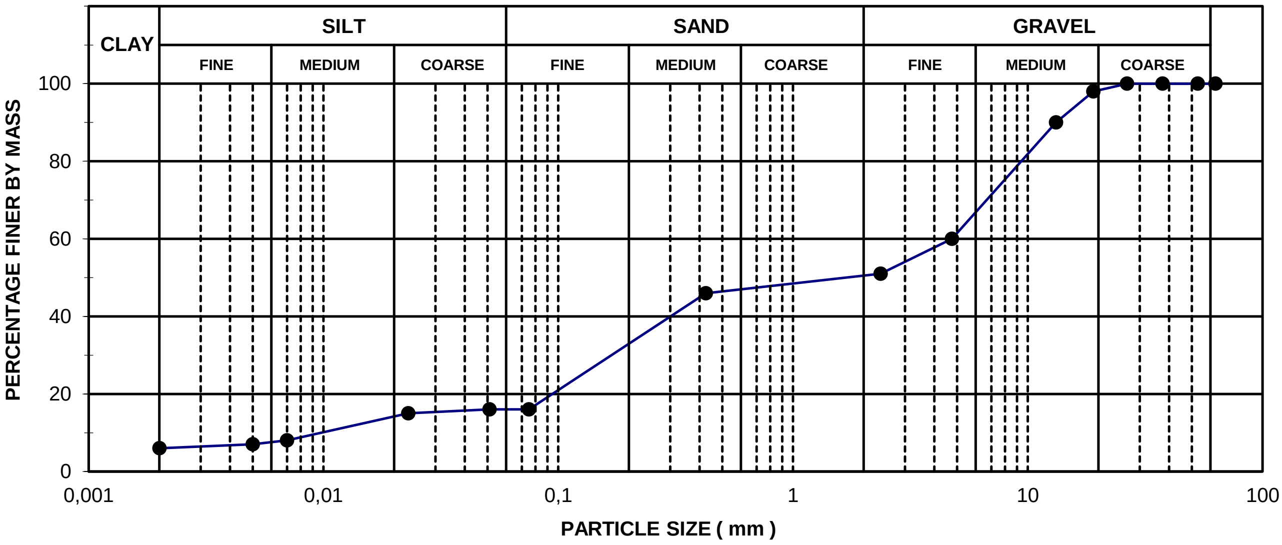


FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	EB TP 46	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13927	PROJECT NUMBER	113834
DEPTH	0,6-0,9 m	SITE	Ebenhaeser Scheme

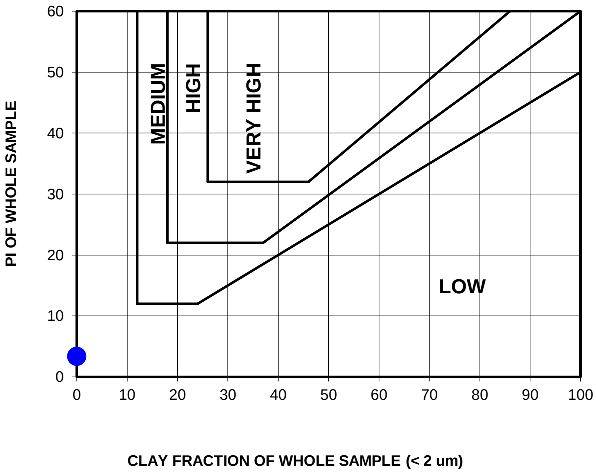
SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**46**	Liquid limit	(%)	**37,0**	% Gravel	**49**
53,000	**100**	0,075	**16**	Plastic limit	(%)	**30**	% Sand	**35**
37,500	**100**	0,051	**16**	Plasticity Index	(%)	**7**	% Silt	**10**
26,500	**100**	0,023	**15**	Weighted PI	(%)	**3**	% Clay	**6**
19,000	**98**	0,007	**8**	Linear Shrinkage	(%)	**3,6**	Activity	**1,2**
13,200	**90**	0,002	**6**	Grading Modulus		**1,87**	Unified Classification	**SM**
4,750	**60**	0,000	**0**	Uniformity coefficient		**252**	TRB Classification	**A - 2 - 4**
2,360	**51**	0,000	**0**	Coefficient of curvature		**0,6**		

PARTICLE SIZE DISTRIBUTION

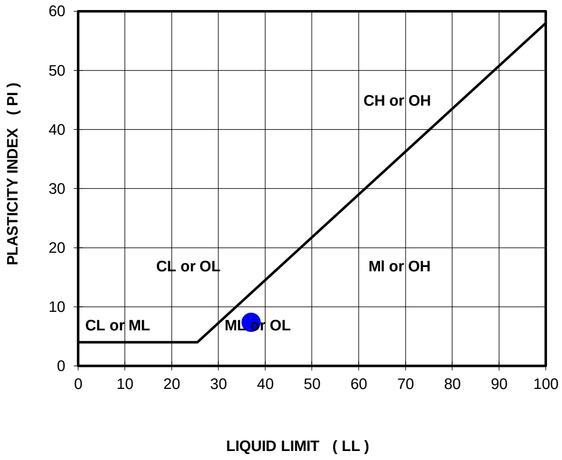


POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE

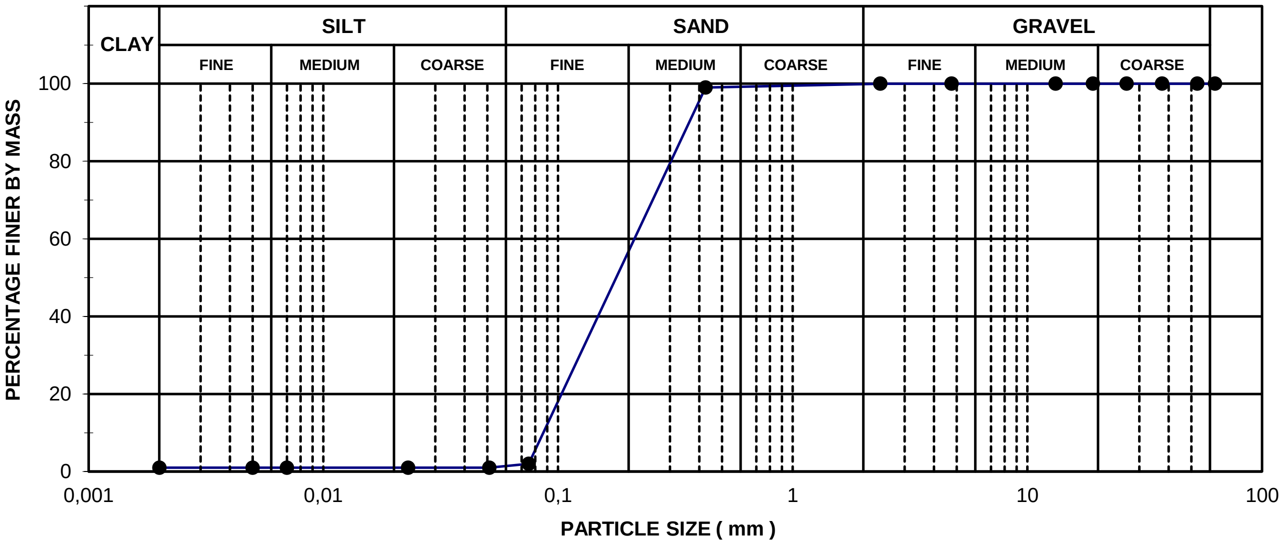


FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	EB TP 48	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13928	PROJECT NUMBER	113834
DEPTH	0.0 - 1.1 m	SITE	Ebenhaeser Scheme

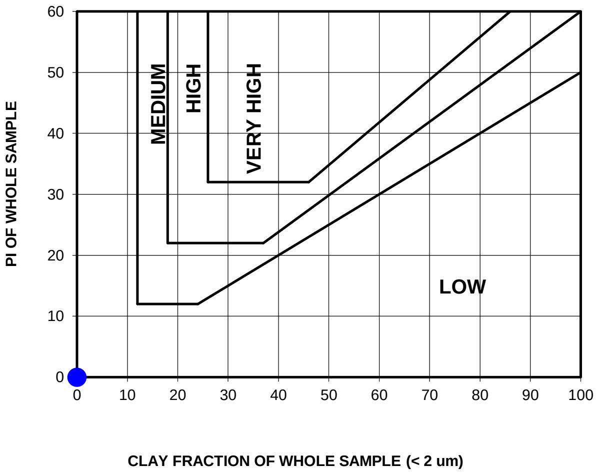
SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**99**	Liquid limit	(%)	**0,0**	% Gravel	**0**
53,000	**100**	0,075	**2**	Plastic limit	(%)	**0**	% Sand	**98**
37,500	**100**	0,051	**1**	Plasticity Index	(%)	**0**	% Silt	**1**
26,500	**100**	0,023	**1**	Weighted PI	(%)	**0**	% Clay	**1**
19,000	**100**	0,007	**1**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**100**	0,002	**1**	Grading Modulus		**0,99**	Unified Classification	
4,750	**100**	0,000	**0**	Uniformity coefficient		**3**	TRB Classification	**A - 3**
2,360	**100**	0,000	**0**	Coefficient of curvature		**1,1**		

PARTICLE SIZE DISTRIBUTION

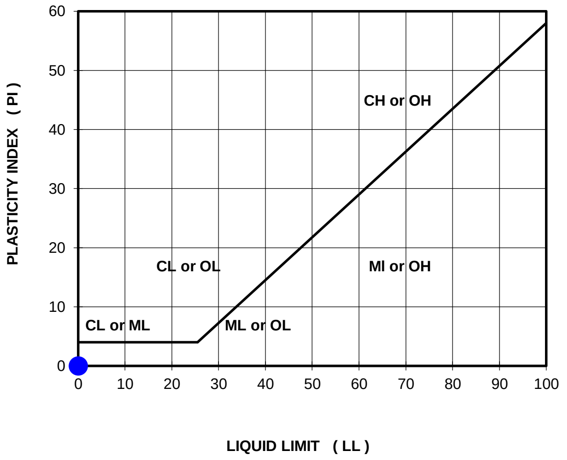


POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE



FOUNDATION INDICATOR TEST RESULTS

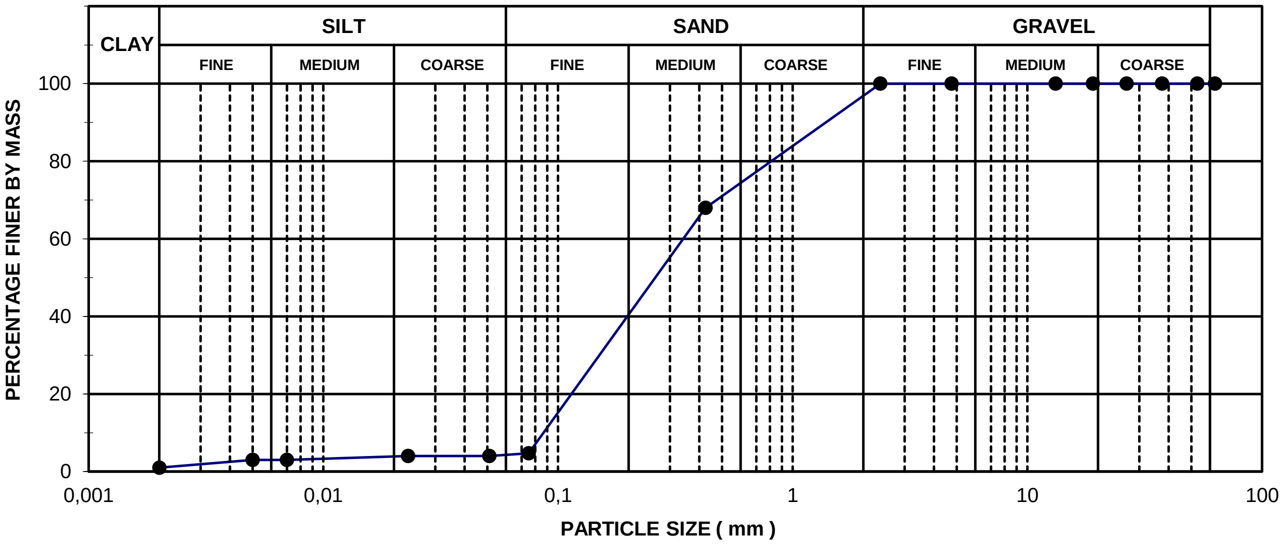
TEST LOCATION	EB TP 52	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13929	PROJECT NUMBER	113834
DEPTH	0,0-0,60 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS			
Sieve (mm)	% Passing	Sieve (mm)	% Passing
63,000	**100**	0,425	**68**
53,000	**100**	0,075	**5**
37,500	**100**	0,051	**4**
26,500	**100**	0,023	**4**
19,000	**100**	0,007	**3**
13,200	**100**	0,002	**1**
4,750	**100**	0,000	**0**
2,360	**100**	0,000	**0**

ATTERBERG LIMITS		
Liquid limit	(%)	**0,0**
Plastic limit	(%)	**0**
Plasticity Index	(%)	**0**
Weighted PI	(%)	**0**
Linear Shrinkage	(%)	**0,0**
Grading Modulus		**1,27**
Uniformity coefficient		**4**
Coefficient of curvature		**1,2**

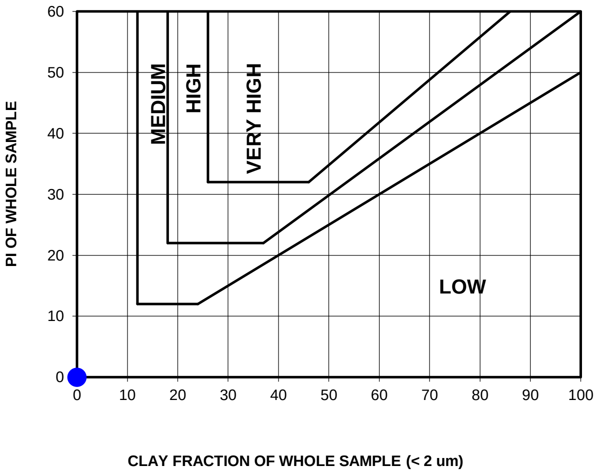
SOIL CLASSIFICATION	
% Gravel	**0**
% Sand	**95**
% Silt	**4**
% Clay	**1**
Activity	**0,0**
Unified Classification	
TRB Classification	**A - 3**

PARTICLE SIZE DISTRIBUTION

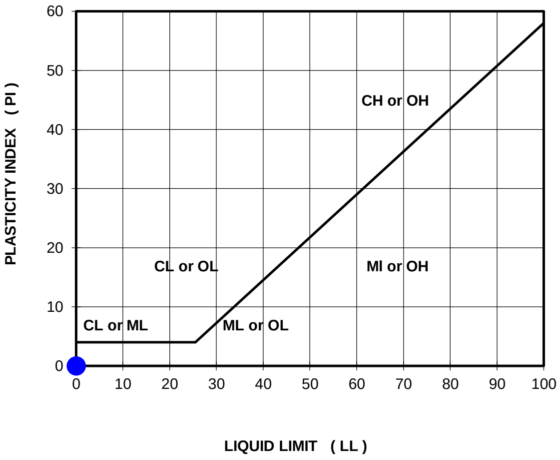


POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE

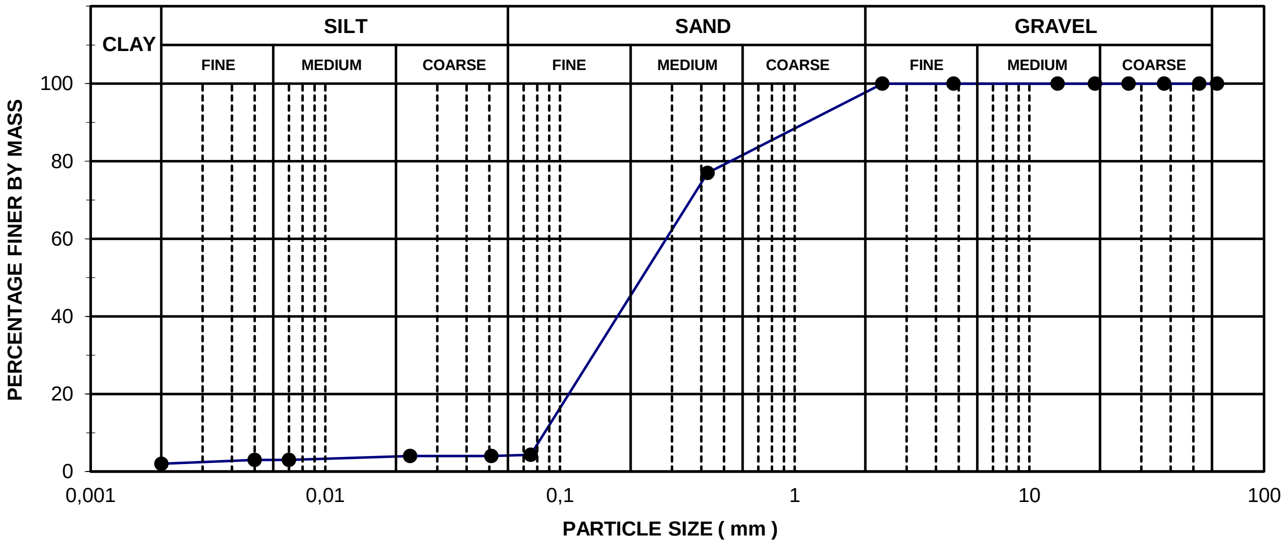


FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	EB TP 53	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13930	PROJECT NUMBER	113834
DEPTH	0,0-1,5 m	SITE	Ebenhaeser Scheme

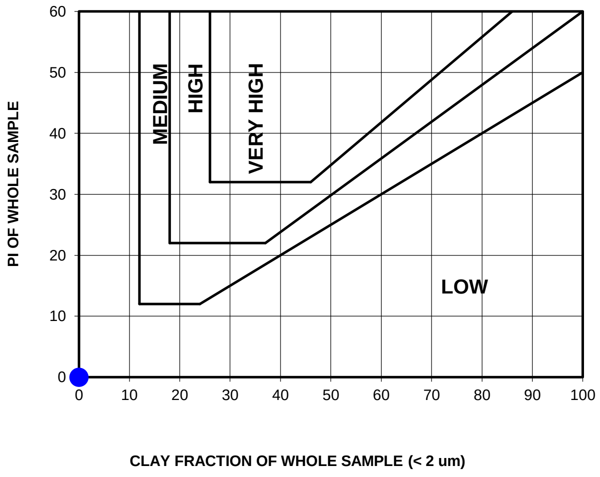
SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**77**	Liquid limit	(%)	**0,0**	% Gravel	**0**
53,000	**100**	0,075	**4**	Plastic limit	(%)	**0**	% Sand	**96**
37,500	**100**	0,051	**4**	Plasticity Index	(%)	**0**	% Silt	**2**
26,500	**100**	0,023	**4**	Weighted PI	(%)	**0**	% Clay	**2**
19,000	**100**	0,007	**3**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**100**	0,002	**2**	Grading Modulus		**1,19**	Unified Classification	
4,750	**100**	0,000	**0**	Uniformity coefficient		**3**	TRB Classification	**A - 3**
2,360	**100**	0,000	**0**	Coefficient of curvature		**1,1**		

PARTICLE SIZE DISTRIBUTION

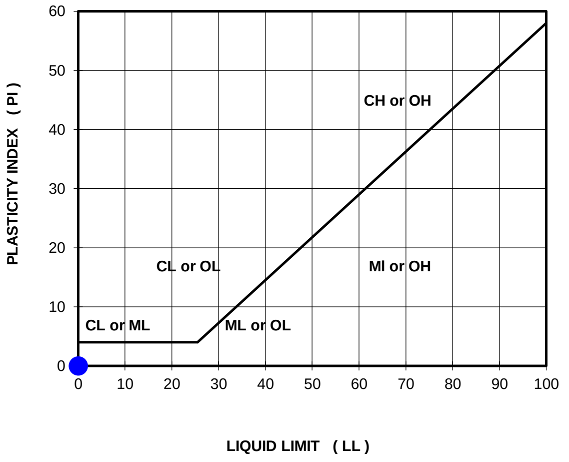


POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE

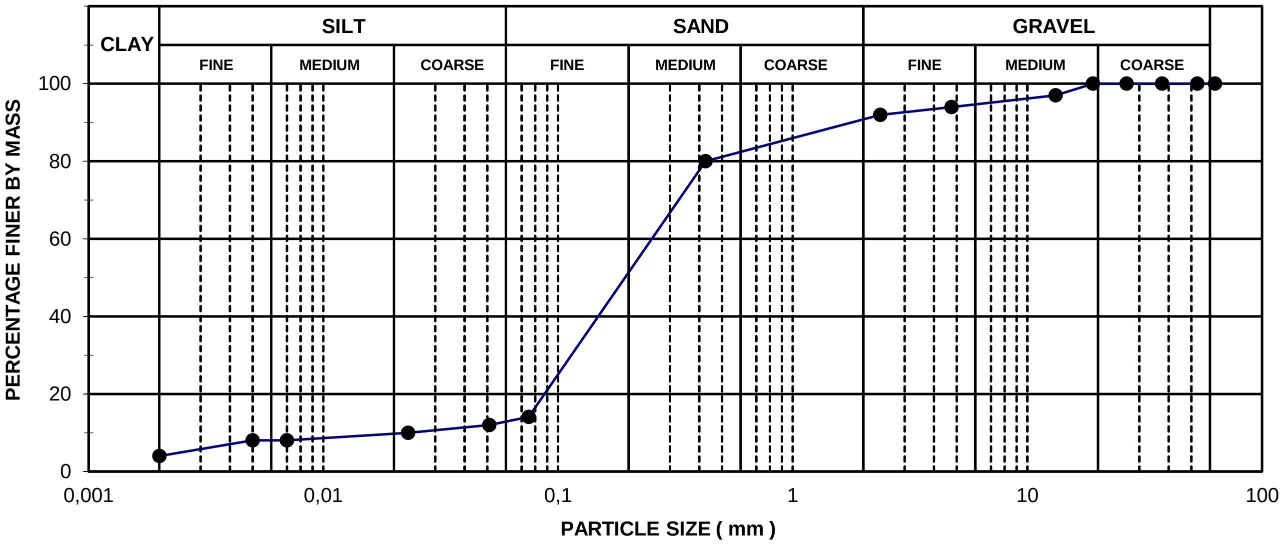


FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	EB TP 57	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13931	PROJECT NUMBER	113834
DEPTH	0,5-1,9 m	SITE	Ebenhaeser Scheme

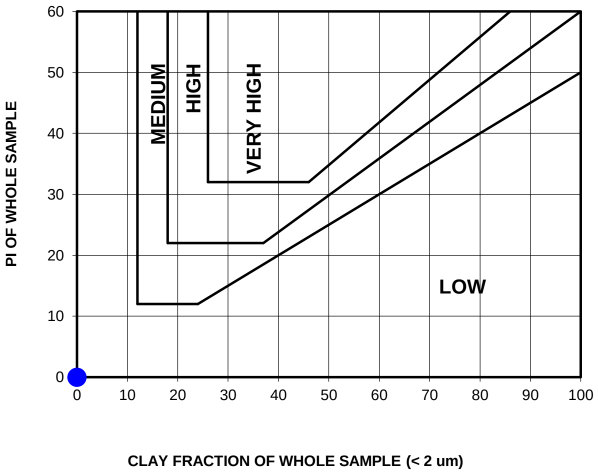
SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**80**	Liquid limit	(%)	**0,0**	% Gravel	**8**
53,000	**100**	0,075	**14**	Plastic limit	(%)	**0**	% Sand	**78**
37,500	**100**	0,051	**12**	Plasticity Index	(%)	**0**	% Silt	**10**
26,500	**100**	0,023	**10**	Weighted PI	(%)	**0**	% Clay	**4**
19,000	**100**	0,007	**8**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**97**	0,002	**4**	Grading Modulus		**1,14**	Unified Classification	**SM**
4,750	**94**	0,000	**0**	Uniformity coefficient		**10**	TRB Classification	**A - 2 - 4**
2,360	**92**	0,000	**0**	Coefficient of curvature		**2,6**		

PARTICLE SIZE DISTRIBUTION

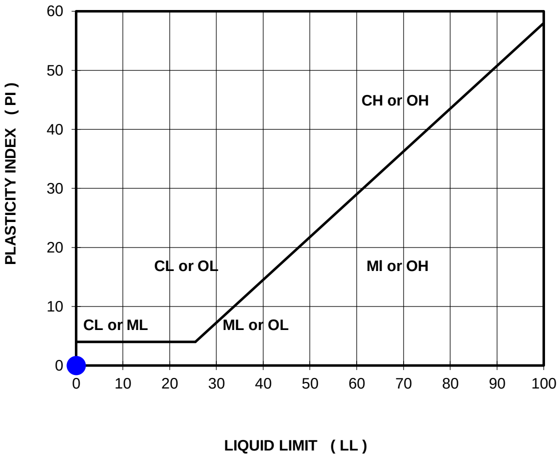


POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE



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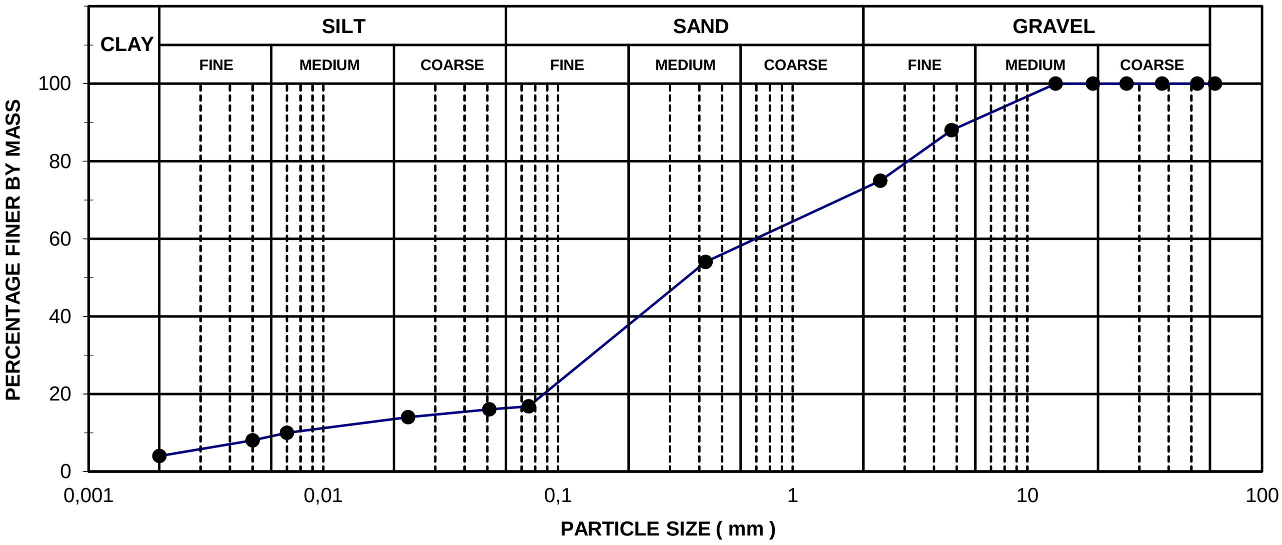
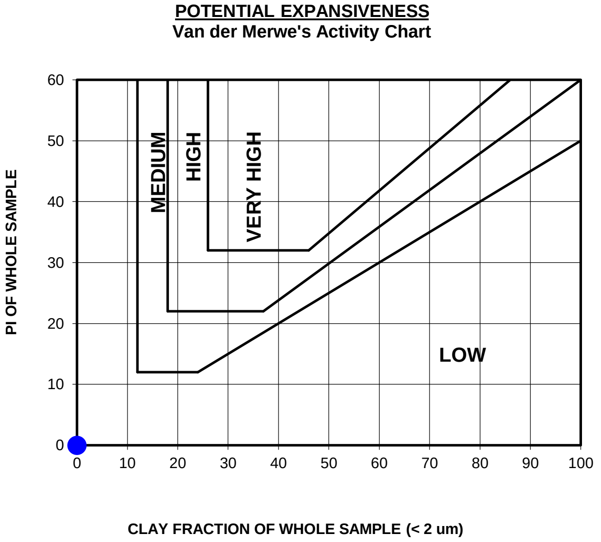
FOUNDATION INDICATOR TEST RESULTS

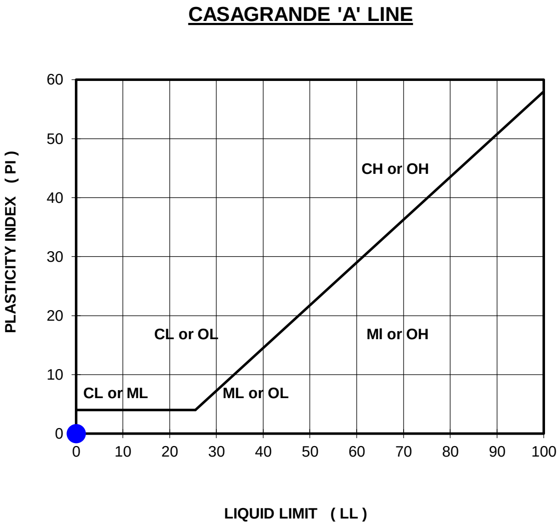
TEST LOCATION	EB TP 59	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13932	PROJECT NUMBER	113834
DEPTH	0,20-1,50 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**54**	Liquid limit	(%)	**0,0**	% Gravel	**25**
53,000	**100**	0,075	**17**	Plastic limit	(%)	**0**	% Sand	**58**
37,500	**100**	0,051	**16**	Plasticity Index	(%)	**0**	% Silt	**13**
26,500	**100**	0,023	**14**	Weighted PI	(%)	**0**	% Clay	**4**
19,000	**100**	0,007	**10**	Linear Shrinkage	(%)	**1,2**	Activity	**0,0**
13,200	**100**	0,002	**4**	Grading Modulus		**1,54**	Unified Classification	**SM**
4,750	**88**	0,000	**0**	Uniformity coefficient		**70**	TRB Classification	**A - 2 - 4**
2,360	**75**	0,000	**0**	Coefficient of curvature		**3,0**		

PARTICLE SIZE DISTRIBUTION







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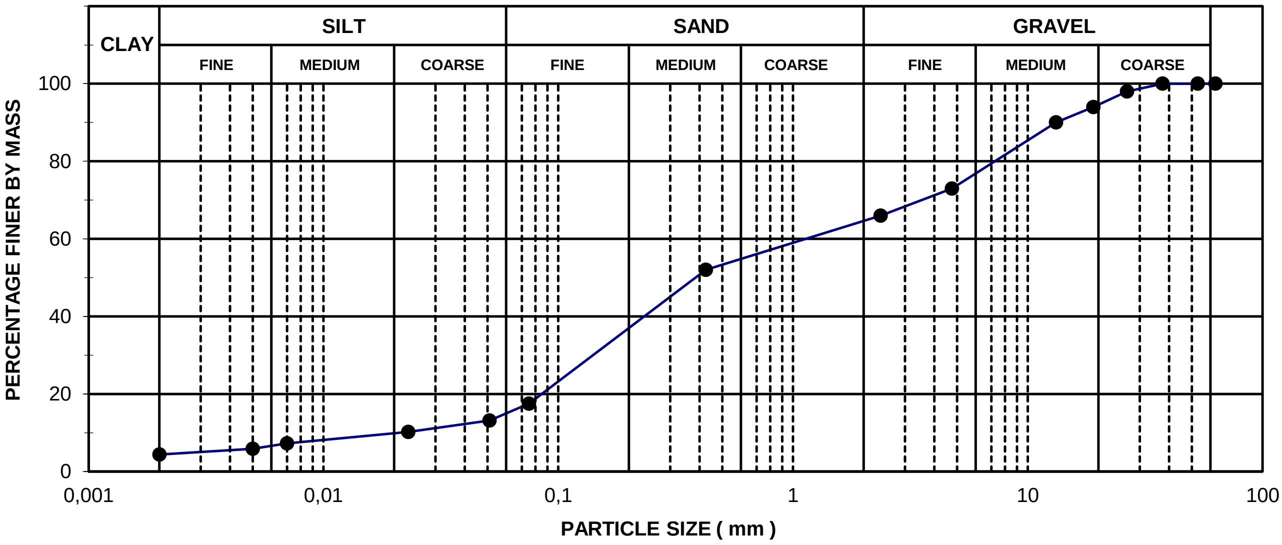
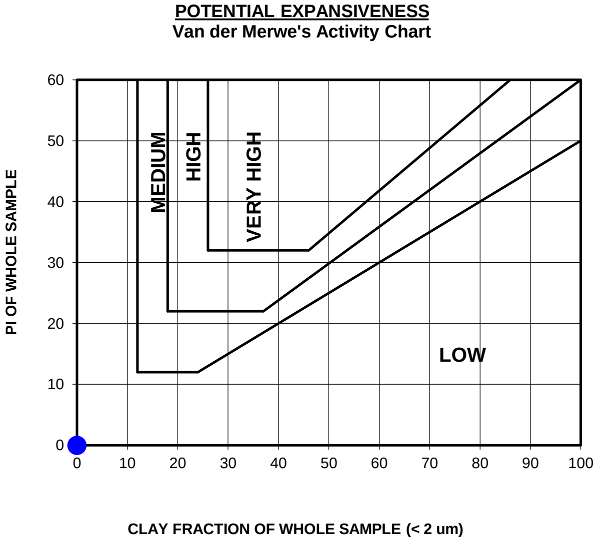
FOUNDATION INDICATOR TEST RESULTS

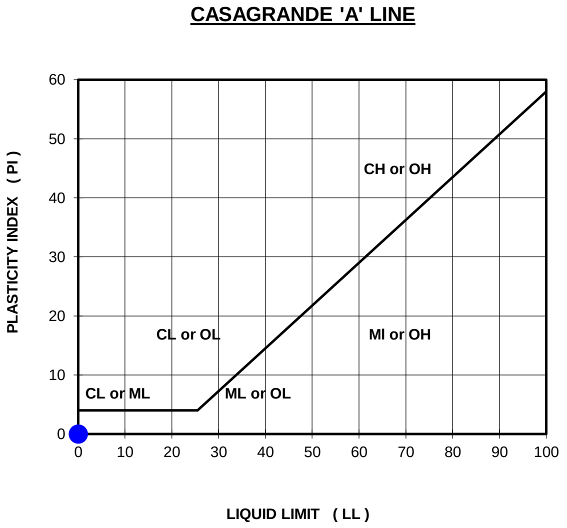
TEST LOCATION	EB TP 61	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13933	PROJECT NUMBER	113834
DEPTH	0,5-2,1 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**52**	Liquid limit	(%)	**0,0**	% Gravel	**34**
53,000	**100**	0,075	**18**	Plastic limit	(%)	**0**	% Sand	**49**
37,500	**100**	0,051	**13**	Plasticity Index	(%)	**0**	% Silt	**13**
26,500	**98**	0,023	**10**	Weighted PI	(%)	**0**	% Clay	**4**
19,000	**94**	0,007	**7**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**90**	0,002	**4**	Grading Modulus		**1,65**	Unified Classification	**SM**
4,750	**73**	0,000	**0**	Uniformity coefficient		**52**	TRB Classification	**A - 2 - 4**
2,360	**66**	0,000	**0**	Coefficient of curvature		**0,9**		

PARTICLE SIZE DISTRIBUTION





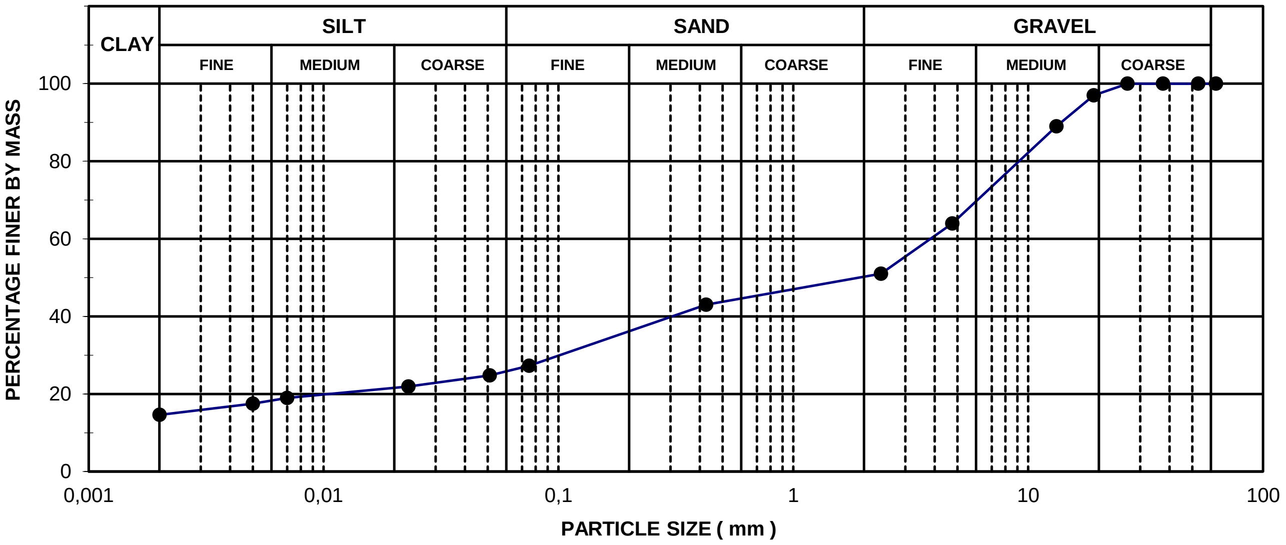


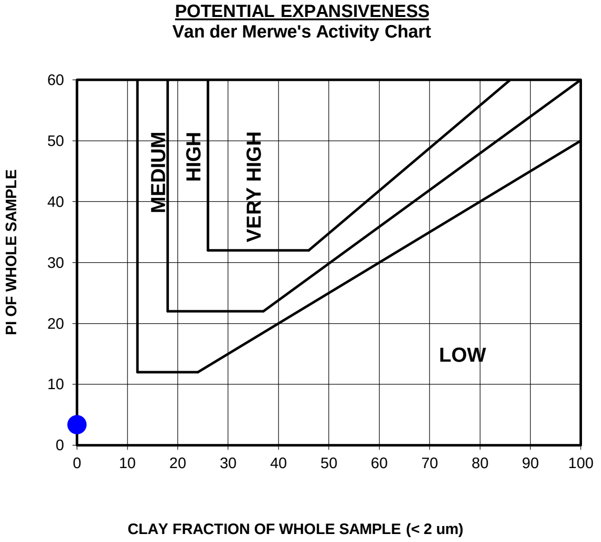
FOUNDATION INDICATOR TEST RESULTS

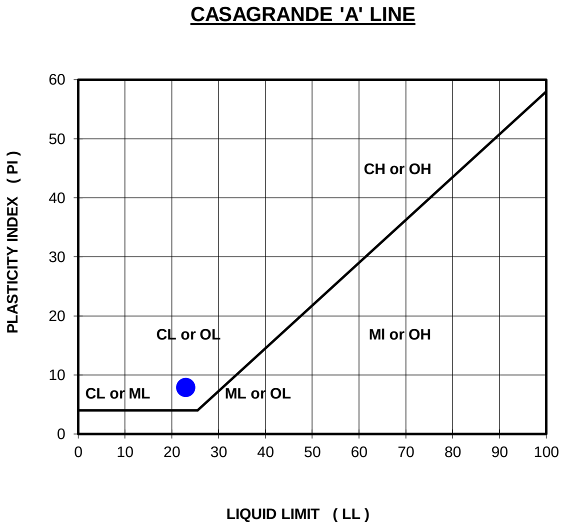
TEST LOCATION	EB TP 63	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13934	PROJECT NUMBER	113834
DEPTH	0,0-0,6 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**43**	Liquid limit	(%)	**23,0**	% Gravel	**49**
53,000	**100**	0,075	**27**	Plastic limit	(%)	**15**	% Sand	**24**
37,500	**100**	0,051	**25**	Plasticity Index	(%)	**8**	% Silt	**13**
26,500	**100**	0,023	**22**	Weighted PI	(%)	**3**	% Clay	**15**
19,000	**97**	0,007	**19**	Linear Shrinkage	(%)	**3,8**	Activity	**0,5**
13,200	**89**	0,002	**15**	Grading Modulus		**1,79**	Unified Classification	**SC**
4,750	**64**	0,000	**0**	Uniformity coefficient		**2007**	TRB Classification	**A - 2 - 4**
2,360	**51**	0,000	**0**	Coefficient of curvature		**2,3**		

PARTICLE SIZE DISTRIBUTION





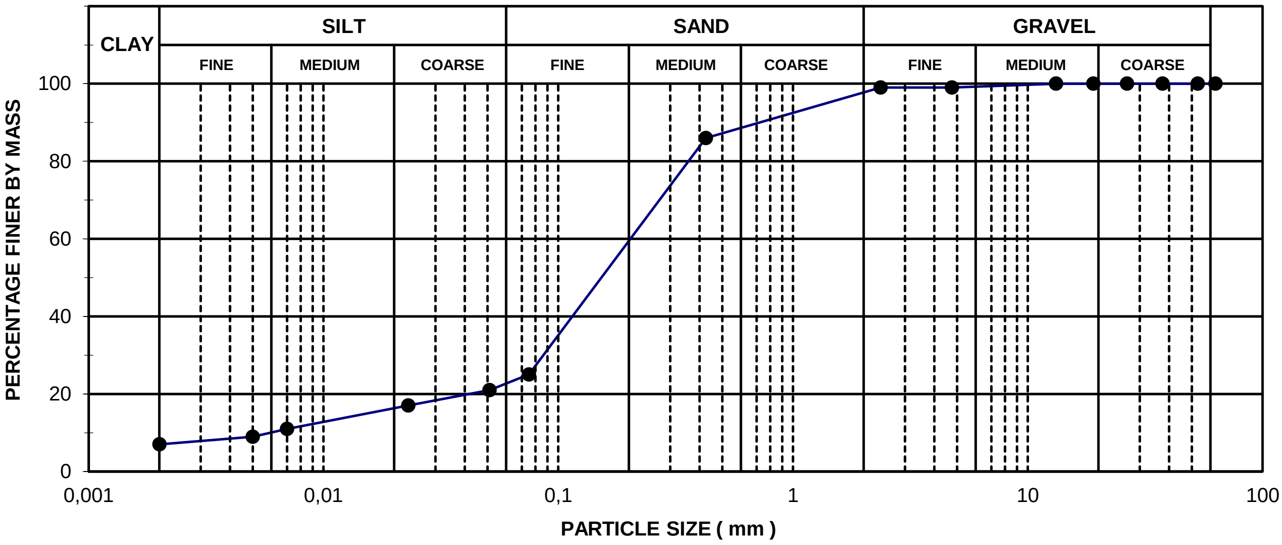


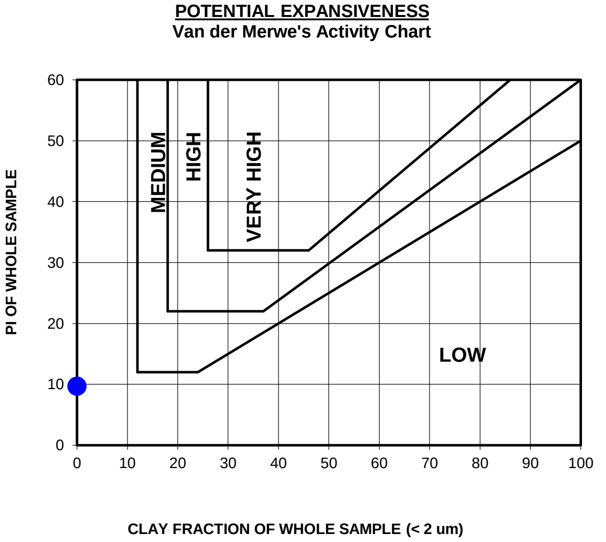
FOUNDATION INDICATOR TEST RESULTS

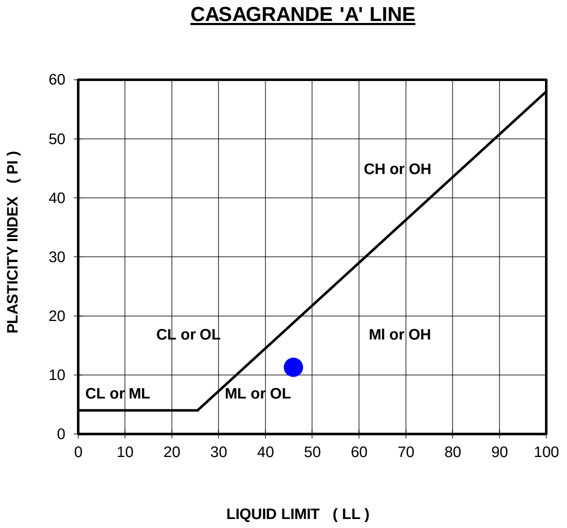
TEST LOCATION	EB TP 66	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13935	PROJECT NUMBER	113834
DEPTH	0,0-0,5 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**86**	Liquid limit	(%)	**46,0**	% Gravel	**1**
53,000	**100**	0,075	**25**	Plastic limit	(%)	**35**	% Sand	**74**
37,500	**100**	0,051	**21**	Plasticity Index	(%)	**11**	% Silt	**18**
26,500	**100**	0,023	**17**	Weighted PI	(%)	**10**	% Clay	**7**
19,000	**100**	0,007	**11**	Linear Shrinkage	(%)	**5,8**	Activity	**1,6**
13,200	**100**	0,002	**7**	Grading Modulus		**0,90**	Unified Classification	**SM**
4,750	**99**	0,000	**0**	Uniformity coefficient		**26**	TRB Classification	**A - 2 - 7**
2,360	**99**	0,000	**0**	Coefficient of curvature		**3,9**		

PARTICLE SIZE DISTRIBUTION





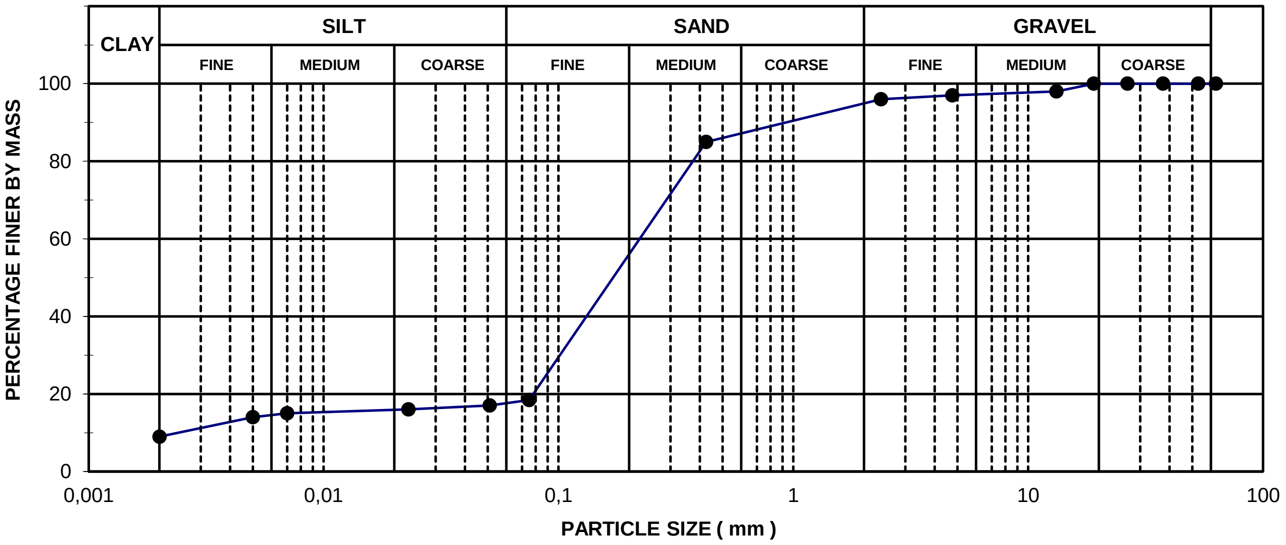


FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	EB TP 72	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13956	PROJECT NUMBER	113834
DEPTH	0,6-1,3 m	SITE	Ebenhaeser Scheme

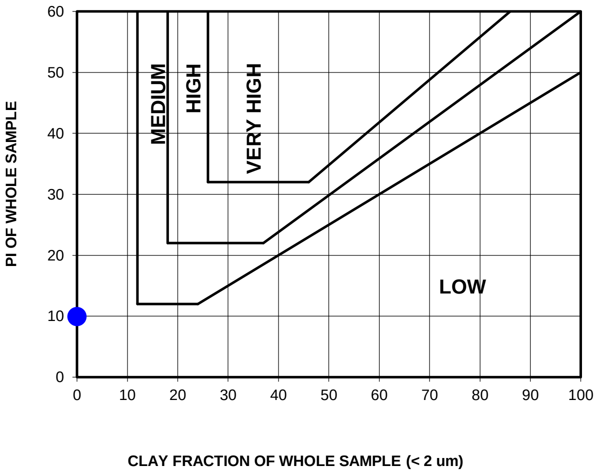
SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**85**	Liquid limit	(%)	**38,0**	% Gravel	**4**
53,000	**100**	0,075	**18**	Plastic limit	(%)	**26**	% Sand	**78**
37,500	**100**	0,051	**17**	Plasticity Index	(%)	**12**	% Silt	**9**
26,500	**100**	0,023	**16**	Weighted PI	(%)	**10**	% Clay	**9**
19,000	**100**	0,007	**15**	Linear Shrinkage	(%)	**5,3**	Activity	**1,3**
13,200	**98**	0,002	**9**	Grading Modulus		**1,01**	Unified Classification	**SM**
4,750	**97**	0,000	**0**	Uniformity coefficient		**113**	TRB Classification	**A - 2 - 6**
2,360	**96**	0,000	**0**	Coefficient of curvature		**24,9**		

PARTICLE SIZE DISTRIBUTION

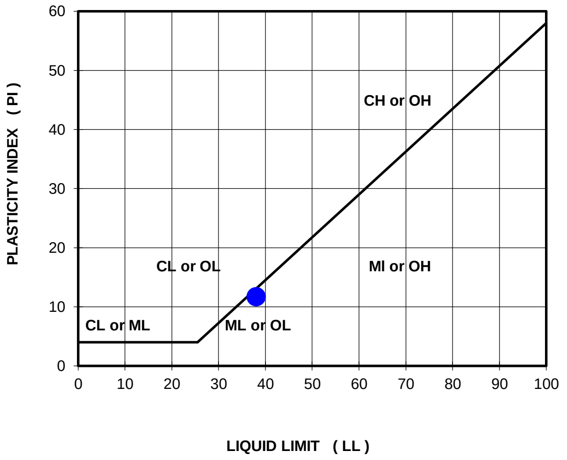


POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE

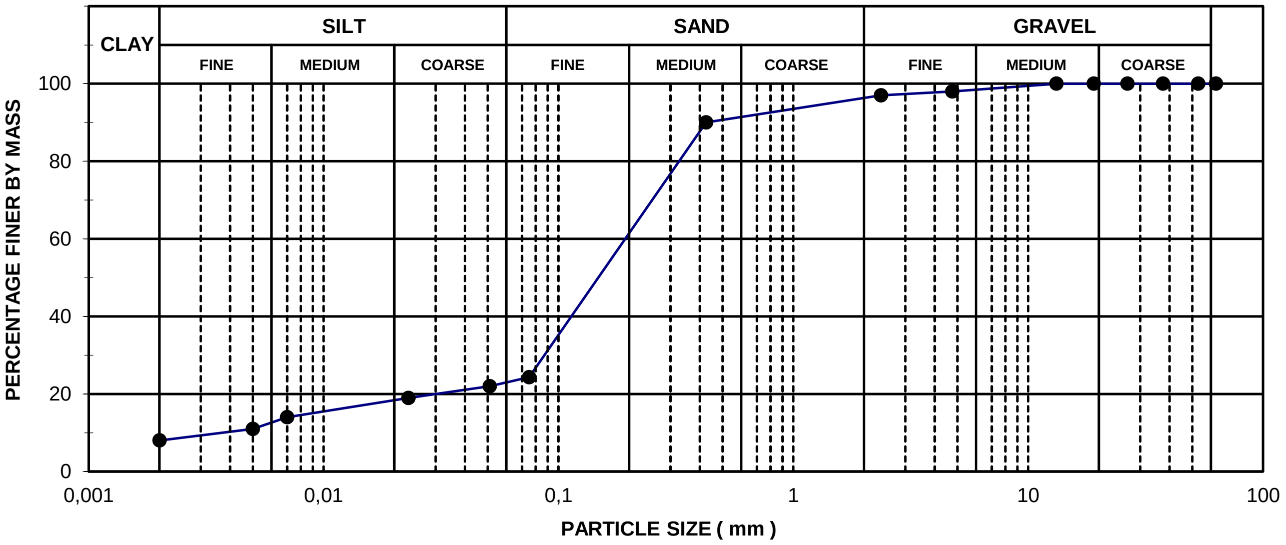


FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	EB TP 73	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13937	PROJECT NUMBER	113834
DEPTH	0,0-0,40 m	SITE	Ebenhaeser Scheme

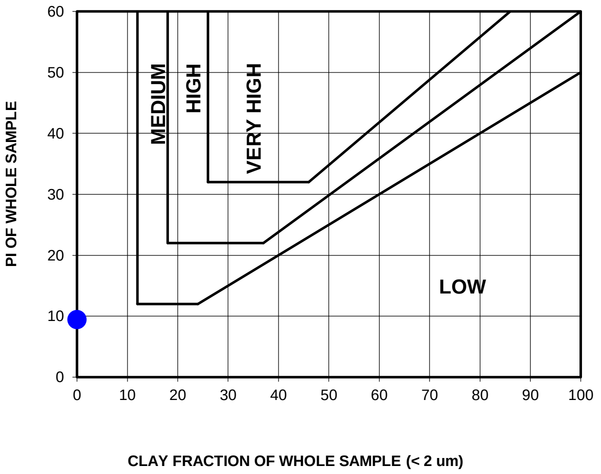
SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**90**	Liquid limit	(%)	**33,0**	% Gravel	**3**
53,000	**100**	0,075	**24**	Plastic limit	(%)	**23**	% Sand	**73**
37,500	**100**	0,051	**22**	Plasticity Index	(%)	**11**	% Silt	**16**
26,500	**100**	0,023	**19**	Weighted PI	(%)	**9**	% Clay	**8**
19,000	**100**	0,007	**14**	Linear Shrinkage	(%)	**4,9**	Activity	**1,3**
13,200	**100**	0,002	**8**	Grading Modulus		**0,89**	Unified Classification	**SC**
4,750	**98**	0,000	**0**	Uniformity coefficient		**66**	TRB Classification	**A - 2 - 6**
2,360	**97**	0,000	**0**	Coefficient of curvature		**10,9**		

PARTICLE SIZE DISTRIBUTION

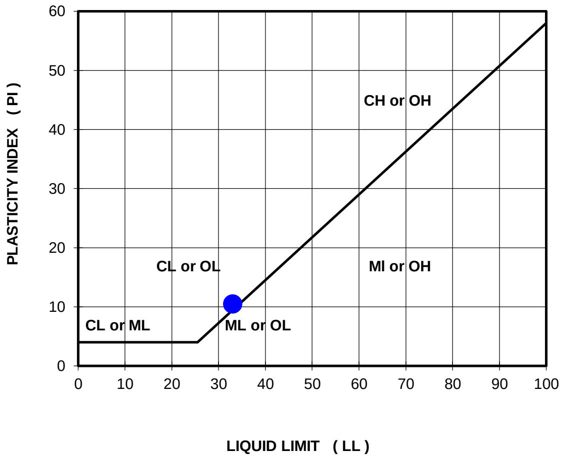


POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE

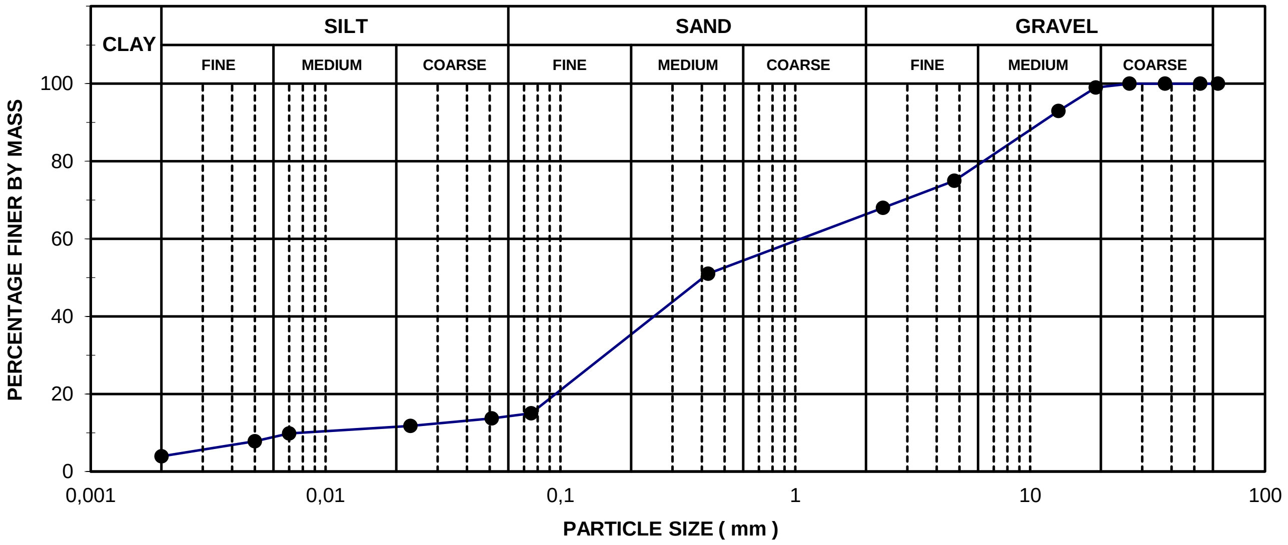


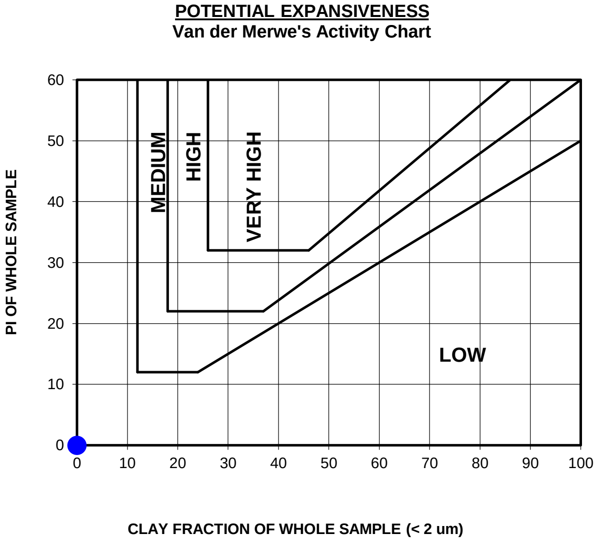
FOUNDATION INDICATOR TEST RESULTS

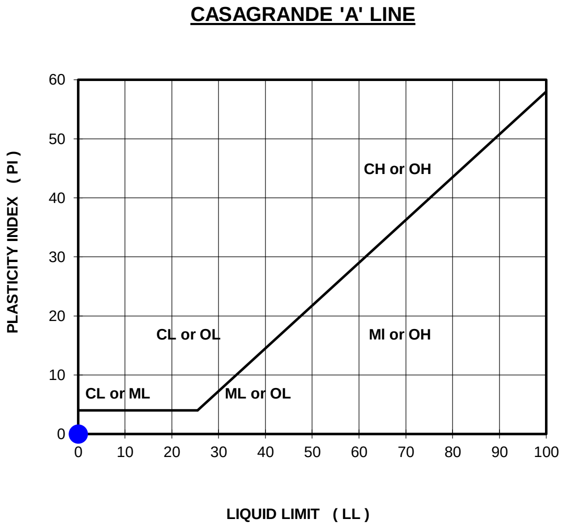
TEST LOCATION	EB TP 78	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13936	PROJECT NUMBER	113834
DEPTH	0,3-0,6 m	SITE	Ebenhaeser Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63,000	**100**	0,425	**51**	Liquid limit	(%)	**0,0**	% Gravel	**32**
53,000	**100**	0,075	**15**	Plastic limit	(%)	**0**	% Sand	**53**
37,500	**100**	0,051	**14**	Plasticity Index	(%)	**0**	% Silt	**11**
26,500	**100**	0,023	**12**	Weighted PI	(%)	**0**	% Clay	**4**
19,000	**99**	0,007	**10**	Linear Shrinkage	(%)	**0,0**	Activity	**0,0**
13,200	**93**	0,002	**4**	Grading Modulus		**1,66**	Unified Classification	**SM**
4,750	**75**	0,000	**0**	Uniformity coefficient		**92**	TRB Classification	**A - 2 - 4**
2,360	**68**	0,000	**0**	Coefficient of curvature		**2,2**		

PARTICLE SIZE DISTRIBUTION







STEYN-WILSON
LABORATORIES
CIVIL ENGINEERING TESTING LABORATORIES

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PO Box 58 Blackheath 7581
Tel: 021 905 0435
Fax: 086 499 9482
Email: admin@steynwilson.co.za
Web: www.steynwilson.co.za

Client: **Zutari**
Project: Ebenhauser
Attention: Ms K Myburgh
Your Ref. No: 113834
Date Reported 26.08.20

TEST REPORT REFERENCE NUMBER / JOB NUMBER : SWL12343

Dear Sir / Madam

Herewith please find the original reports pertaining to the above mentioned project.

Test Requested

4 x FOUNDATION INDICATORS
3 x MOD / CBR
1 x PH & CONDUCTIVITY

Site Sampling and Materials Information

Sampling Method	Specimens delivered to Steyn Wilson Laboratory.
Environmental Condition	Sunny
Deviation from the prescribed test method	
Responsibility of information disclaimer	

● **FINAL REPORT**

We would like to take this opportunity to thank you for your valued support.
Should you have any further enquiries please don't hesitate to contact me.

Yours Faithfully
STEYN-WILSON LABORATORIES (PTY) LTD

Mr. R.Wilson
Technical Signatory

Remarks:
1. Information contained herein is confidential to STEYN-WILSON PTY LTD and the addressee
2. Opinions & Interpretations are not included in our schedule of Accreditation.
3. The samples where subjected and analysed according to ASTM.
4. The results reported relate only to the sample tested, Further use of the attached information is not the responsibility or liability of STEYN-WILSON LABORATORIES (PTY) LTD.
5. This document is the correct record of all measurements made, and may not be reproduced other than with full written approval from a director of STEYN-WILSON LABORATORIES (PTY) LTD.
6. Measuring equipment is traceable to national standards (Where applicable).
7. Should there be any deviation from the prescribed test method comments will be made thereof, pertaining to the test on the relevant materials report.
8. Uncertainty of measurement is calculated and corresponds to a coverage probability of approximately 95%. Available on request.
9. The decision rule states that the measurement of uncertainty can be applied by the customer to the test results, on request. It is not the responsibility or liability of STEYN-WILSON LABORATORIES (PTY) LTD.

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Web: www.steynwilson.co.za

Customer :	**Zutari**	Project :	Ebenhauser
	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	26.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

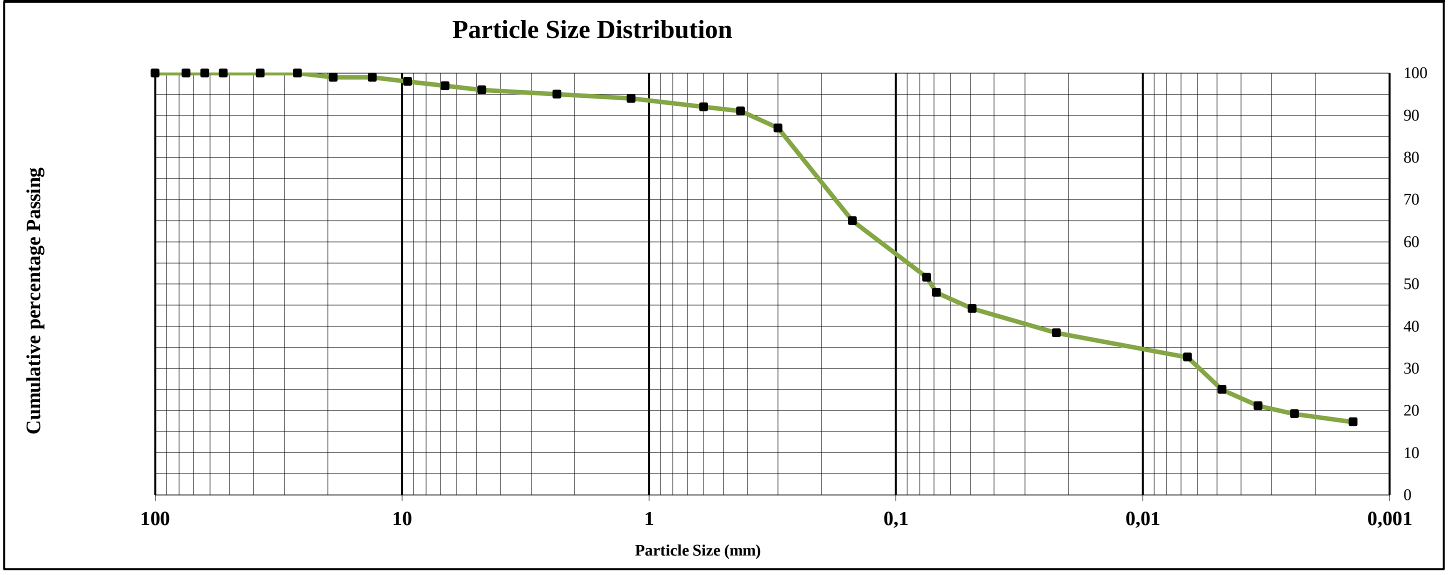
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Light Brown Olive Silty Sand	Sample Number:	13944		
Position:	TP07	Liquid Limit	**27,6**	Linear Shrinkage	**6,3**
Depth:	0.30 - 3.00m	Plasticity Index	**13,3**	Insitu M/C%	**16,3**

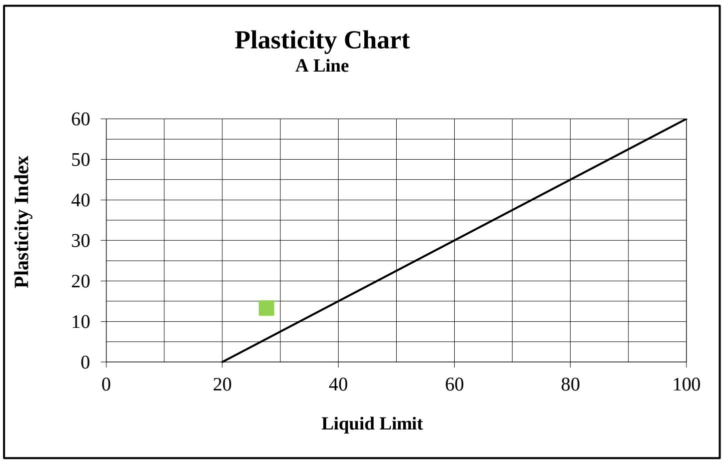
pH (TMH1 A20)*	**8,2**		**Conductivity s.m-¹ (TMH1 A21T)***	**0,014**		**COLTO SPEC**	**G10**

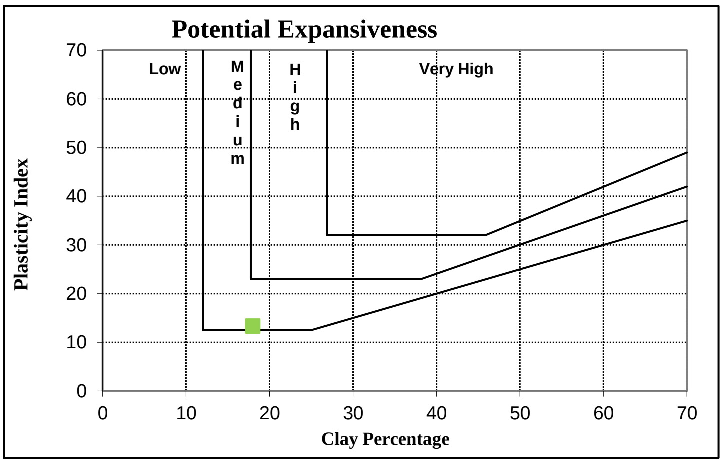
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,068	0,049	0,022	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	99	99	98	97	96	95	94	92	91	87	65	51,6	48	44,16	38,4	32,64	24,96	21,12	19,2	17,28
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%	10,4	**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)	2028	10,8	0,80	10	9	7	7	6	5



% Gravel	**5**	**% Sand**	**49**	**% Silt**	**28**	**% Clay**	**18**





NOTE: All tests marked with (*) means that those test methods are not accredited.

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Customer :	**Zutari**	Project :	Ebenhauser
	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	26.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

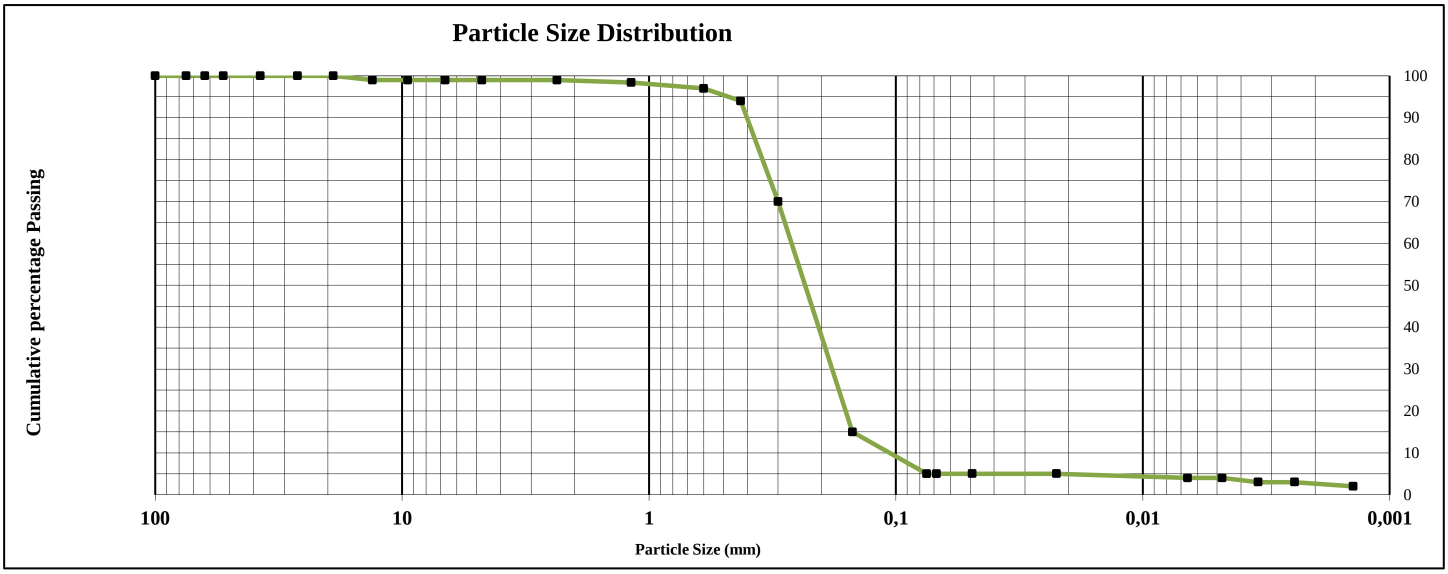
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Brown Reddish Fine Sand	Sample Number:	13945		
Position:	TP09	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.0 - 3.00m	Plasticity Index	**NP**	Insitu M/C%	**1,6**

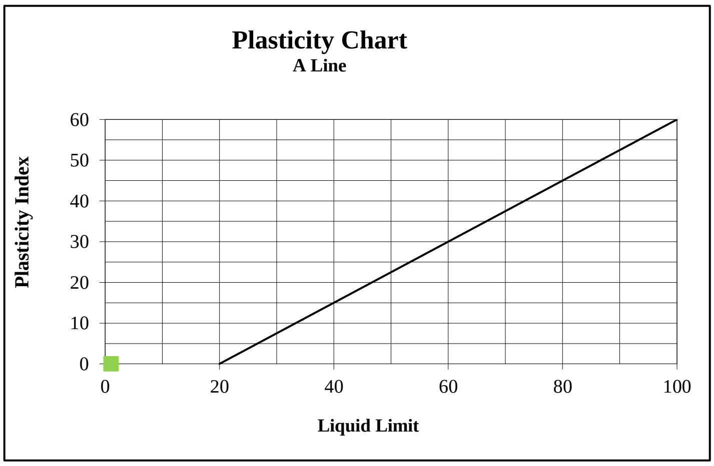
PH (TMH1 A20)*		**(TMH1 A21T)* Conductivity s.m^{-1}**		**COLTO SPEC**	**G9**

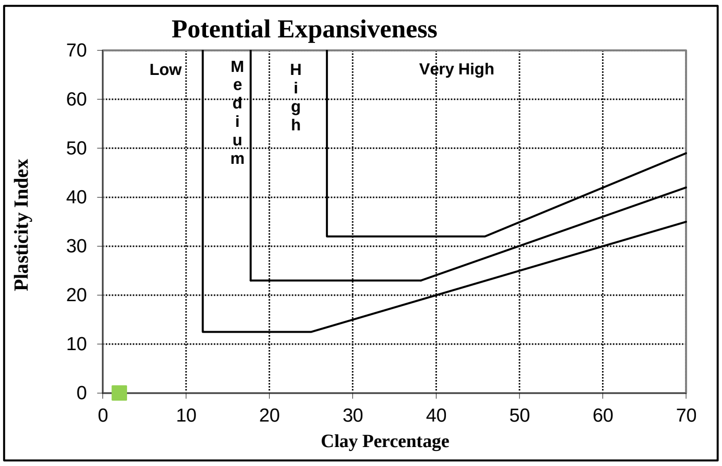
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,068	0,049	0,022	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	99	99	99	99	99	98,4	97	94	70	15	5	5	5	5	4	4	3	3	2
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%	11,6	**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)	1859	11,2	0.0	15	13	12	10	8	6



% Gravel	1	**% Sand**	94	**% Silt**	3	**% Clay**	2





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Customer : **Zutari**
1 Century City Drive
Century City
7446
Attention : Ms K Myburgh

Project : Ebenhauser
Date Received : 01.08.20
Date Reported : 26.08.20
Req. Number : 113834

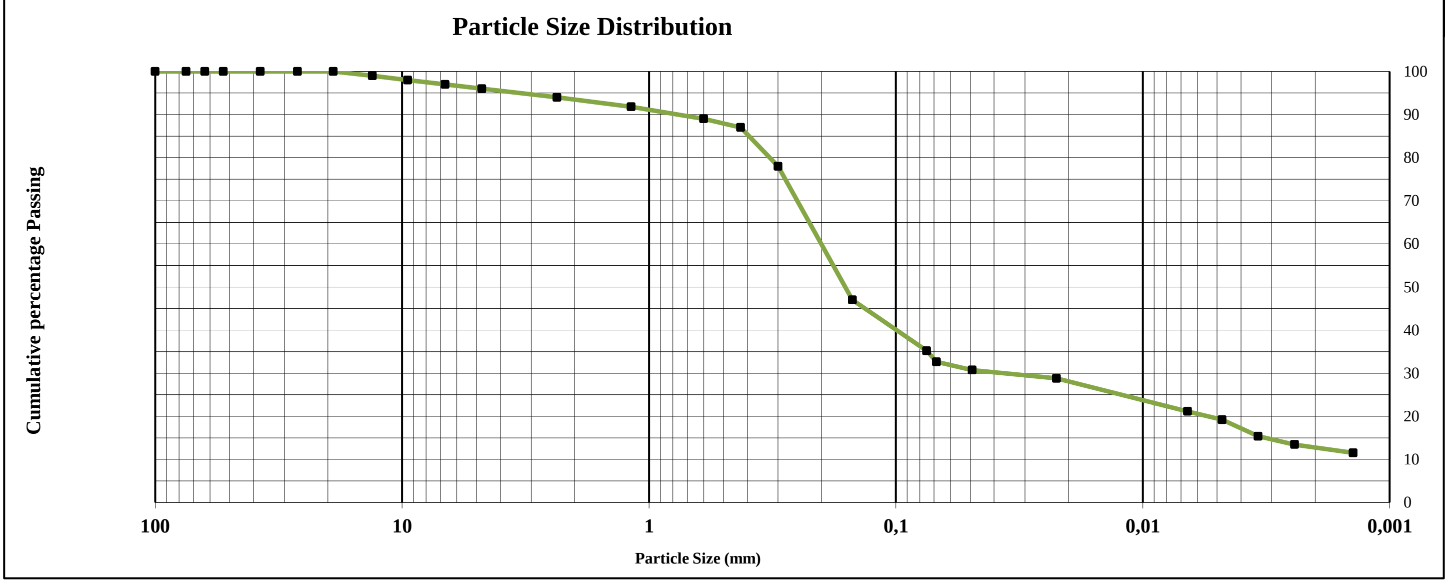
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Light Brown Olive Silty Soil with Calcrete	Sample Number:	13953		
Position:	TP10	Liquid Limit	**35**	Linear Shrinkage	**5,4**
Depth:	1.00 - 2.00m	Plasticity Index	**11,6**	Insitu M/C%	**16,3**

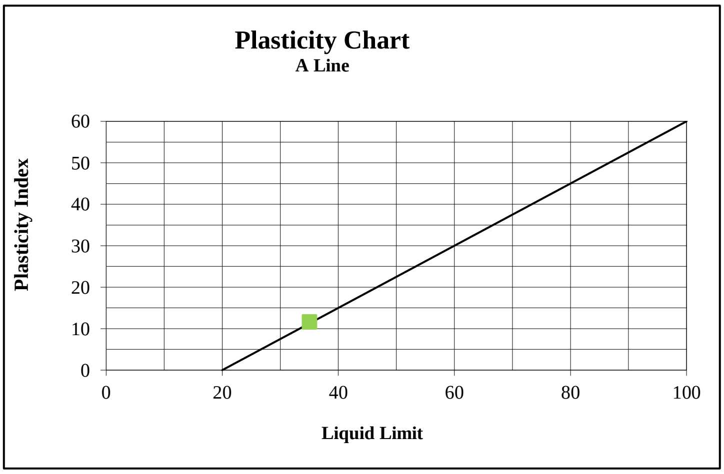
PH (TMH1 A20)*		**(TMH1 A21T)* Conductivity s.m^{-1}**		**COLTO SPEC**	**G10**

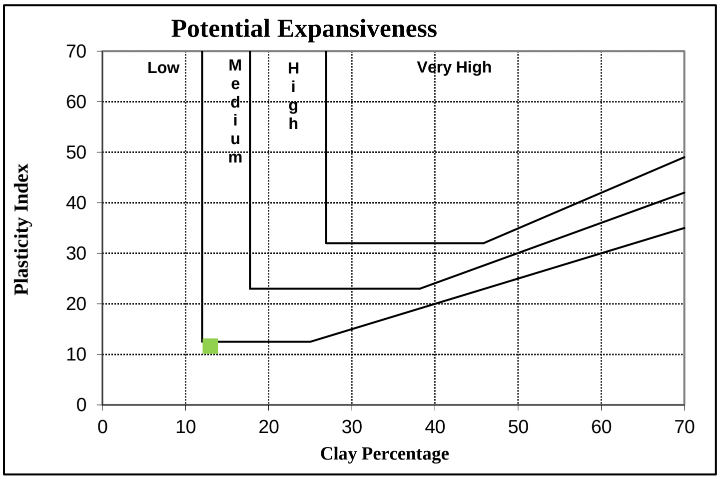
SIEVE ANALYSIS (TMH 1 A1a)*																		HYDROMETER ASTM D422							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,068	0,049	0,022	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	99	98	97	96	94	91,8	89	87	78	47	35,2	32,64	30,72	28,8	21,12	19,2	15,36	13,44	11,52
% Passing																									

MOD AASHTO SANS 3001 GR30		CBR SANS 3001 GR40							
OMC%	10,0	**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)	1970	10,4	0,76	9	7	6	5	4	3



% Gravel	**7**	**% Sand**	**61**	**% Silt**	**19**	**% Clay**	**13**





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Customer :	**Zutari**	Project :	Ebenhauser
	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	26.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

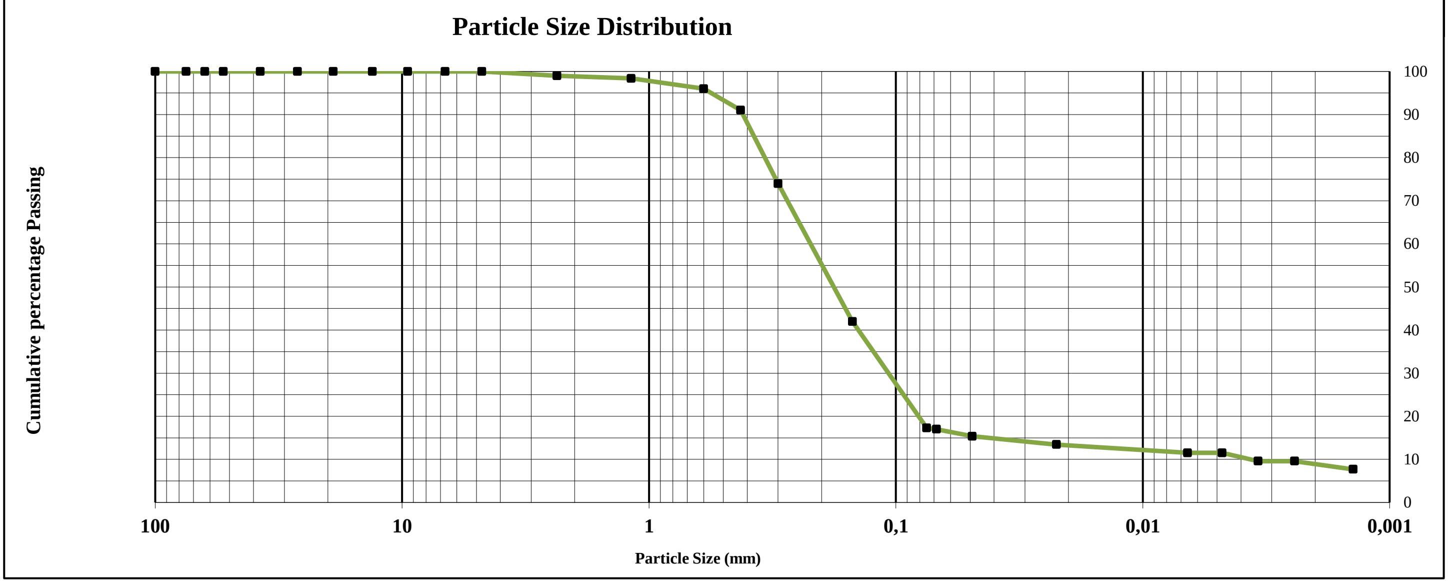
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Brown Reddish Silty Soil	Sample Number:	13950		
Position:	TP11	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.0 - 1.10m	Plasticity Index	**NP**	Insitu M/C%	**5,5**

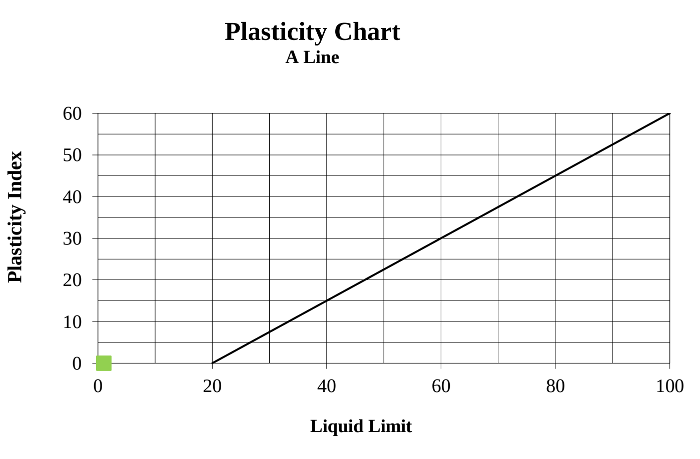
PH (TMH1 A20)*		**(TMH1 A21T)* Conductivity s.m^{-1}**		**COLTO SPEC**	

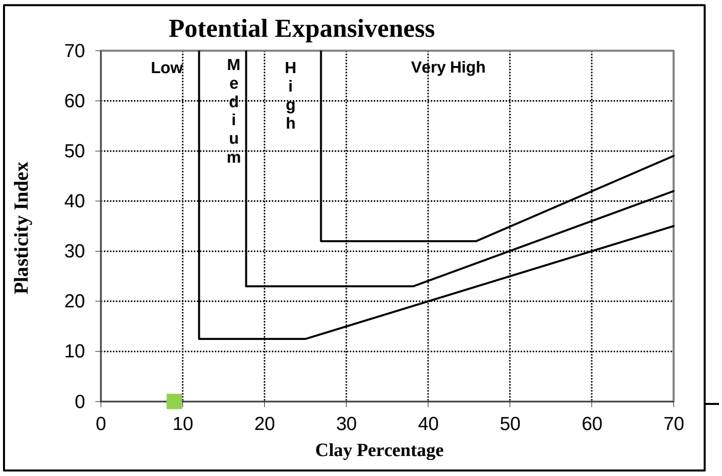
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,068	0,049	0,022	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	100	99	98,4	96	91	74	42	17,3	17	15,36	13,44	11,52	11,52	9,6	9,6	7,68
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel	1	**% Sand**	83	**% Silt**	7	**% Clay**	9





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CIVIL ENGINEERING TESTING LABORATORIES

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PO Box 58 Blackheath 7581
Tel: 021 905 0435
Fax: 086 499 9482
Email: admin@steynwilson.co.za
Web: www.steynwilson.co.za

Client:	**Zutari**
Project:	Ebenhauser
Attention:	Ms K Myburgh
Your Ref. No:	113834
Date Reported	26.08.20

TEST REPORT REFERENCE NUMBER / JOB NUMBER : SWL12343

Dear Sir / Madam

Herewith please find the original reports pertaining to the above mentioned project.

Test Requested

4	*x FOUNDATION INDICATORS*
2	*x MOD / CBR*
4	*x PH & CONDUCTIVITY*

Site Sampling and Materials Information

Sampling Method	Specimens delivered to Steyn Wilson Laboratory.
Environmental Condition	Sunny
Deviation from the prescribed test method	
Responsibility of information disclaimer	

● **FINAL REPORT**

We would like to take this opportunity to thank you for your valued support.
Should you have any further enquiries please don't hesitate to contact me.

Yours Faithfully
STEYN-WILSON LABORATORIES (PTY) LTD

Mr. R.Wilson
Technical Signatory

Remarks:

1. Information contained herein is confidential to STEYN-WILSON PTY LTD and the addressee
2. Opinions & Interpretations are not included in our schedule of Accreditation.
3. The samples where subjected and analysed according to ASTM.
4. The results reported relate only to the sample tested, Further use of the attached information is not the responsibility or liability of STEYN-WILSON LABORATORIES (PTY) LTD.
5. This document is the correct record of all measurements made, and may not be reproduced other than with full written approval from a director of STEYN-WILSON LABORATORIES (PTY) LTD.
6. Measuring equipment is traceable to national standards (Where applicable).
7. Should there be any deviation from the prescribed test method comments will be made thereof, pertaining to the test on the relevant materials report.
8. Uncertainty of measurement is calculated and corresponds to a coverage probability of approximately 95%. Available on request.
9. The decision rule states that the measurement of uncertainty can be applied by the customer to the test results, on request. It is not the responsibility or liability of STEYN-WILSON LABORATORIES (PTY) LTD.

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Customer :	**Zutari**	Project :	Ebenhauser
	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	26.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

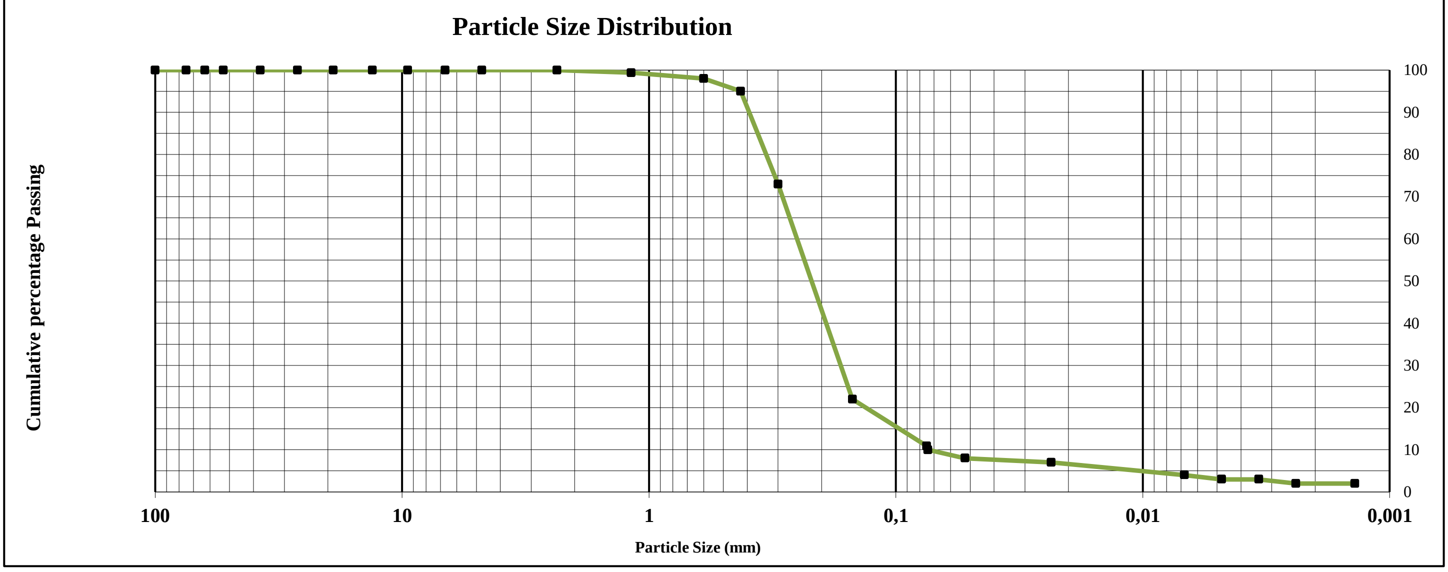
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Dark Brown Silty Soil	Sample Number:	13981		
Position:	TP11	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	1.10 - 1.40m	Plasticity Index	**NP**	Insitu M/C%	**5,4**

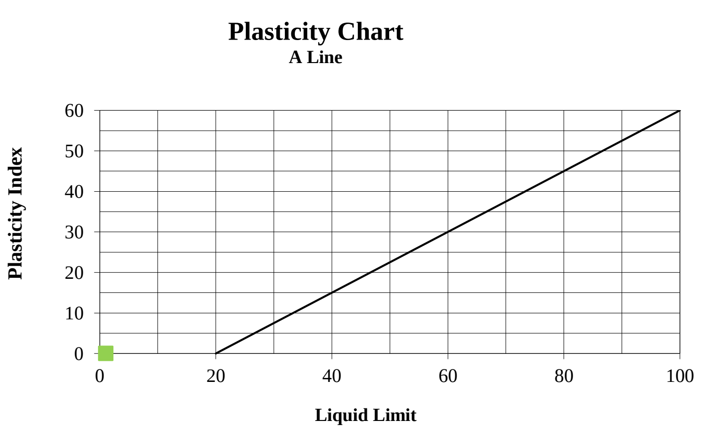
pH (TMH1 A20)*	**7,8**	**Conductivity s.m-1 (TMH1 A21T)***	**0,065**	**COLTO SPEC**	

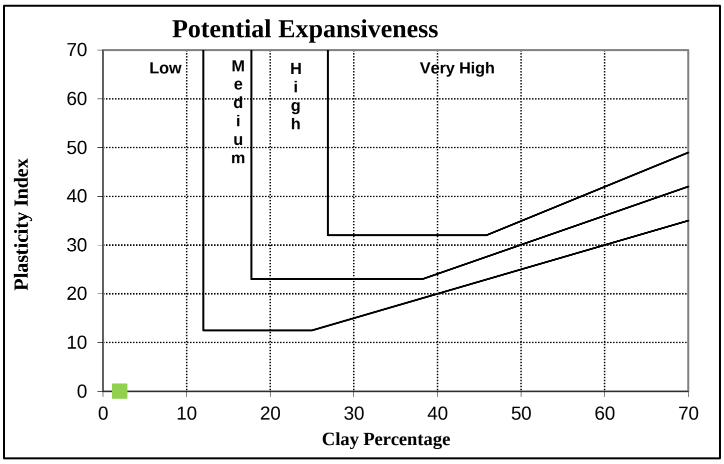
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	100	100	99,4	98	95	73	22	10,9	10	8	7	4	3	3	2	2
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel		**% Sand**	**91**	**% Silt**	**7**	**% Clay**	**2**





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Customer :	**Zutari**	Project :	Ebenhauser
	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	26.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

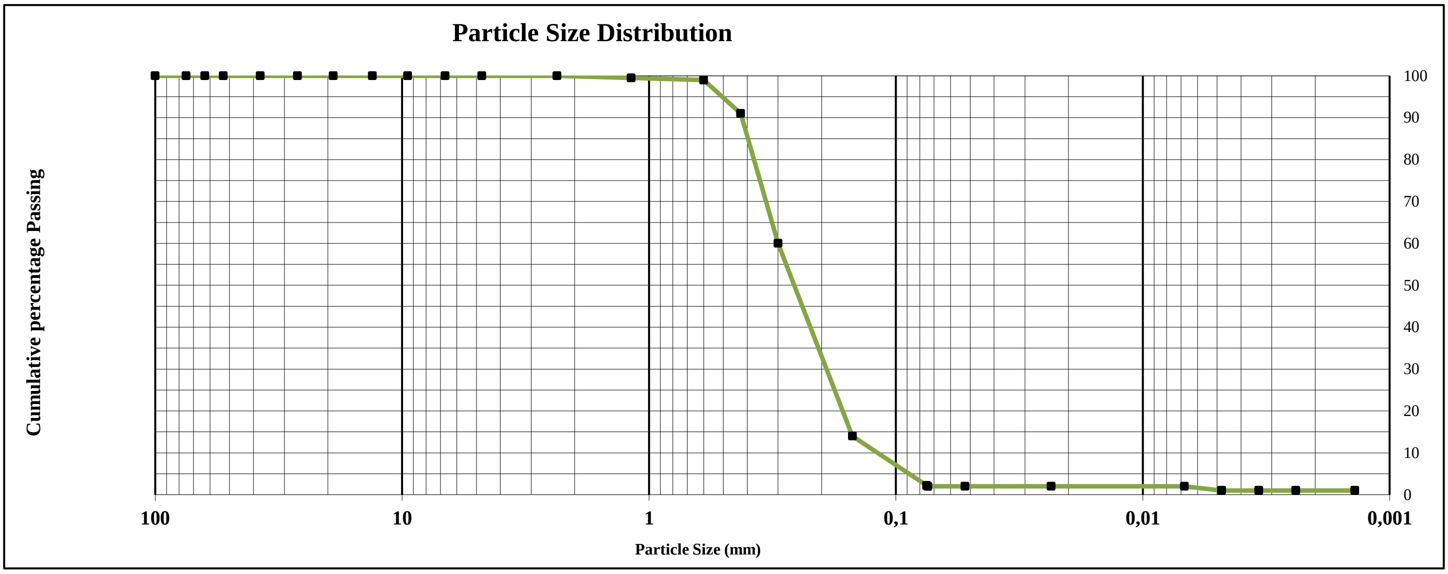
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Dark Brown Orange Soil	Sample Number:	13948		
Position:	TP14	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.0 - 1.70m	Plasticity Index	**NP**	Insitu M/C%	**5,1**

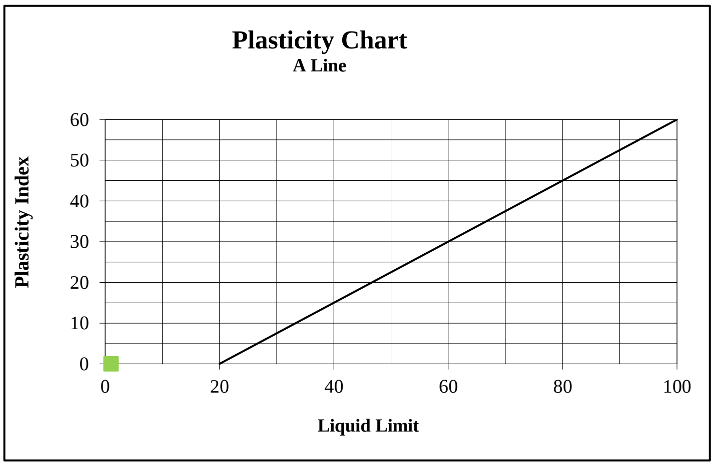
PH (TMH1 A20)*	**7,4**	**(TMH1 A21T)* Conductivity s.m^{-1}**	**0,005**	**COLTO SPEC**	**G8**

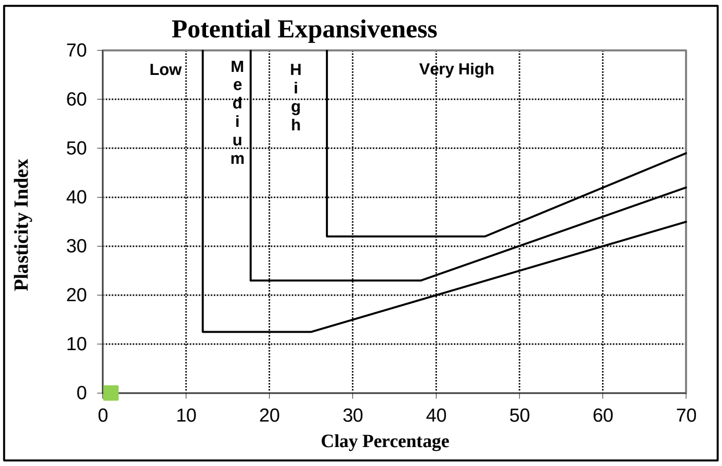
SIEVE ANALYSIS (TMH 1 A1a)*																**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	100	100	99,5	99	91	60	14	2,2	2	2	2	2	1	1	1	1
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%	10,8	**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)	1744	10,4	0.0	17	15	13	12	10	8



% Gravel		**% Sand**	**98**	**% Silt**	**1**	**% Clay**	**1**





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Customer :	**Zutari**	Project :	Ebenhauser
	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	26.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

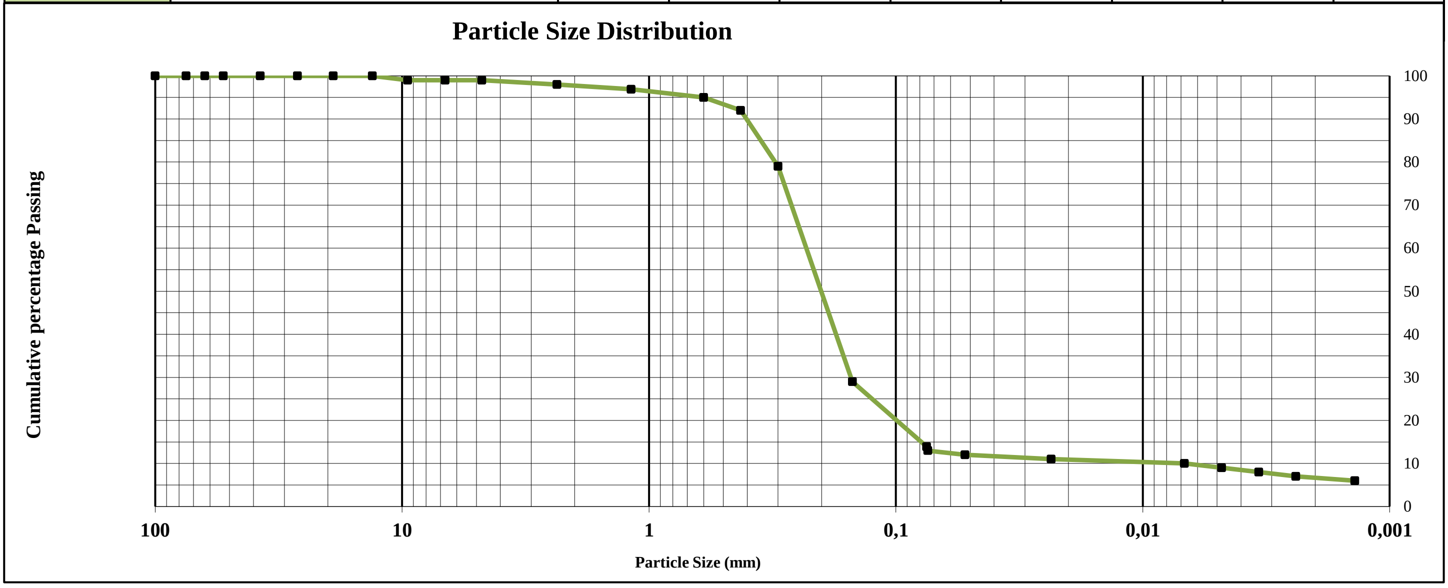
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Dark Brown Orange Sand	Sample Number:	13949		
Position:	TP15	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.0 - 1.40m	Plasticity Index	**NP**	Insitu M/C%	**5,4**

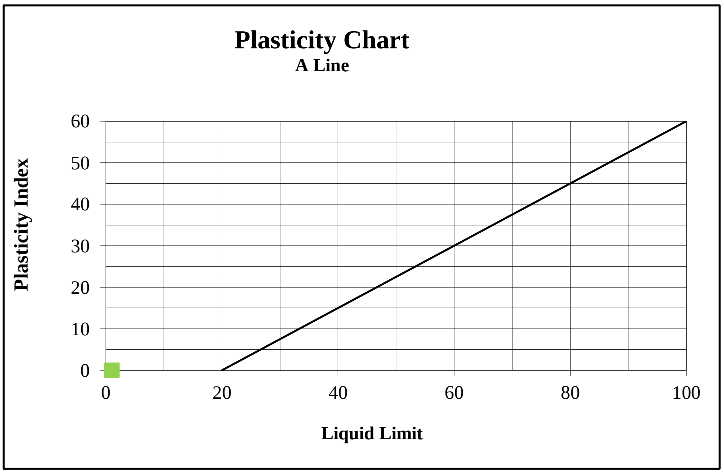
PH (TMH1 A20)*	**8,8**	**(TMH1 A21T)* Conductivity s.m^{-1}**	**0,130**	**COLTO SPEC**	**G9**

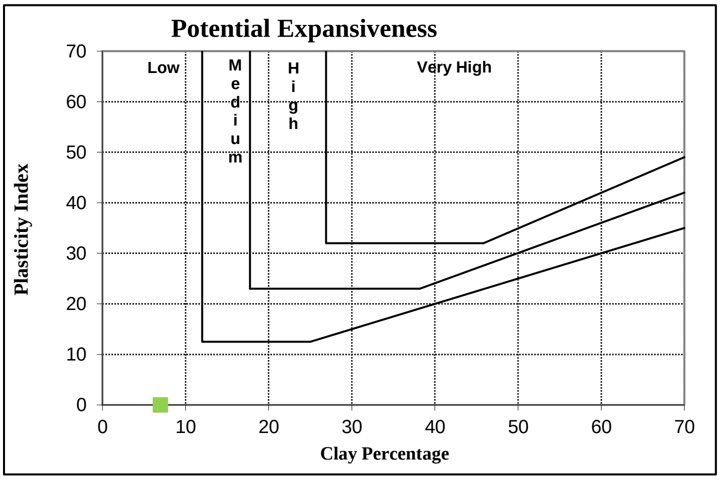
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	99	99	99	98	96,9	95	92	79	29	13,9	13	12	11	10	9	8	7	6
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%	10,4	**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)	2023	10,8	0,0	24	18	15	12	9	6



% Gravel	**2**	**% Sand**	**86**	**% Silt**	**5**	**% Clay**	**7**





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Customer : **Zutari**
1 Century City Drive
Century City
7446
Attention : Ms K Myburgh

Project : Ebenhauser
Date Received : 01.08.20
Date Reported : 26.08.20
Req. Number : 113834

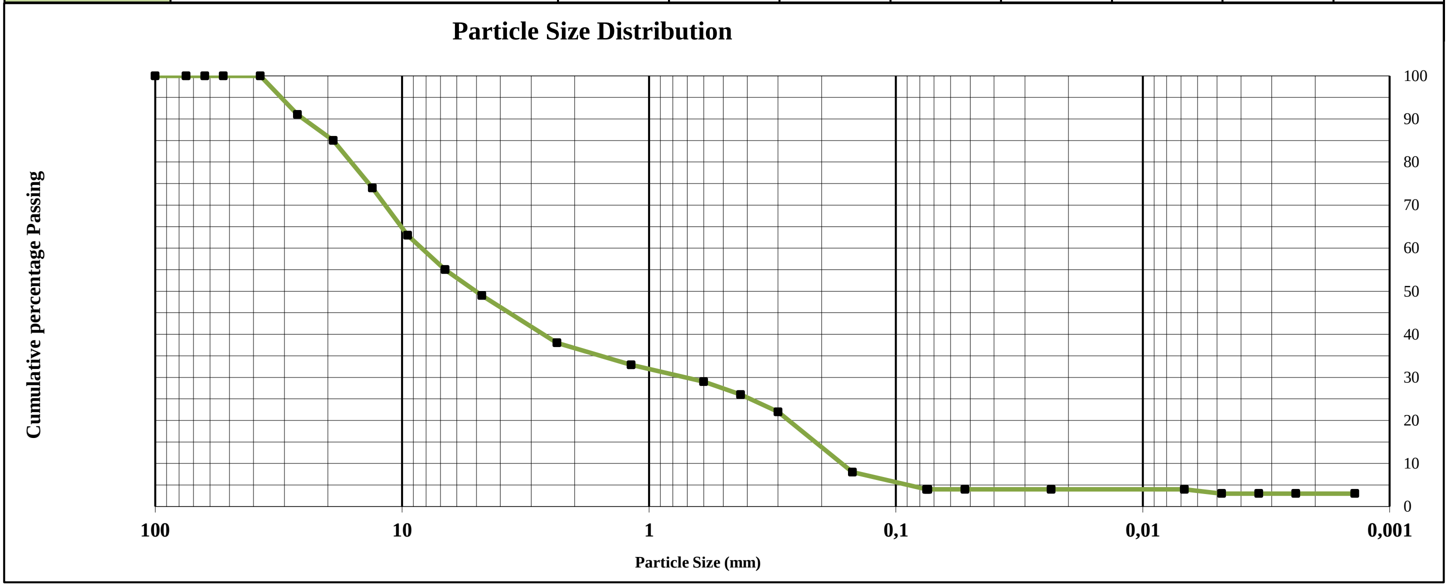
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Dark Brown Orange Soil with Pebbles	Sample Number:	13952		
Position:	TP16	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.3 - 0.5m	Plasticity Index	**NP**	Insitu M/C%	**1,7**

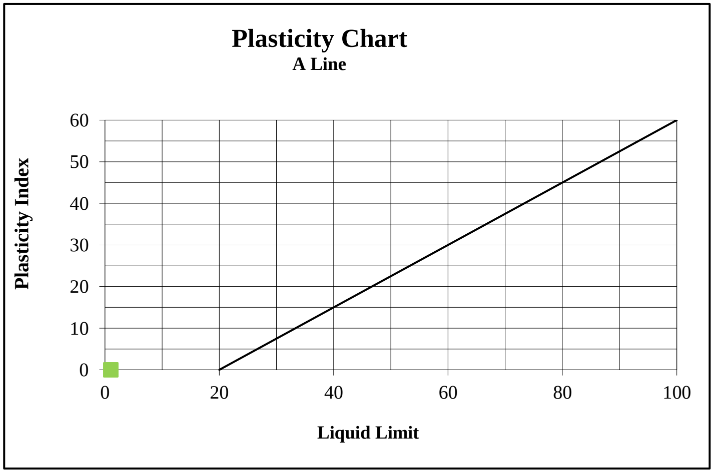
PH (TMH1 A20)*	**5,6**	**(TMH1 A21T)* Conductivity s.m^{-1}**	**0,190**	**COLTO SPEC**	

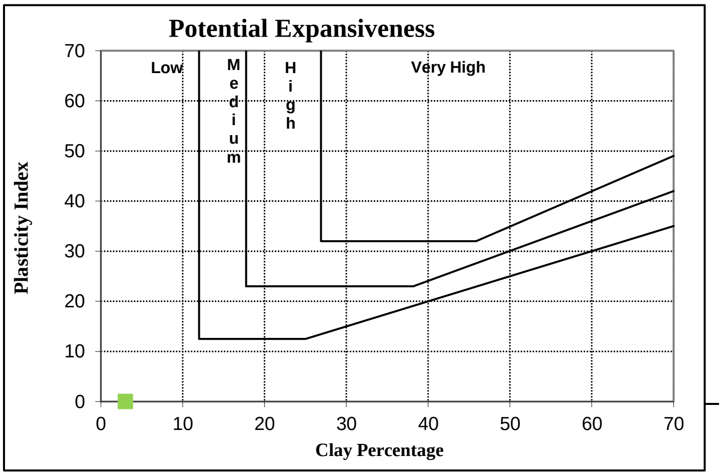
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	91	85	74	63	55	49	38	32,9	29	26	22	8	4	4	4	4	4	3	3	3	3
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel	64	**% Sand**	32	**% Silt**	1	**% Clay**	3





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Email: admin@steynwilson.co.za
Web: www.steynwilson.co.za

Client:	**Zutari**
Project:	Ebenhauser
Attention:	Ms K Myburgh
Your Ref. No:	113834
Date Reported	26.08.20

TEST REPORT REFERENCE NUMBER / JOB NUMBER : SWL12343

Dear Sir / Madam

Herewith please find the original reports pertaining to the above mentioned project.

Test Requested

4	*x FOUNDATION INDICATORS*
2	*x MOD / CBR*
2	*x PH & CONDUCTIVITY*

Site Sampling and Materials Information

Sampling Method	Specimens delivered to Steyn Wilson Laboratory.
Environmental Condition	Sunny
Deviation from the prescribed test method	
Responsibility of information disclaimer	

● **FINAL REPORT**

We would like to take this opportunity to thank you for your valued support.
Should you have any further enquiries please don't hesitate to contact me.

Yours Faithfully
STEYN-WILSON LABORATORIES (PTY) LTD

Mr. R.Wilson
Technical Signatory

Remarks:

1. Information contained herein is confidential to STEYN-WILSON PTY LTD and the addressee
2. Opinions & Interpretations are not included in our schedule of Accreditation.
3. The samples where subjected and analysed according to ASTM.
4. The results reported relate only to the sample tested, Further use of the attached information is not the responsibility or liability of STEYN-WILSON LABORATORIES (PTY) LTD.
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8. Uncertainty of measurement is calculated and corresponds to a coverage probability of approximately 95%. Available on request.
9. The decision rule states that the measurement of uncertainty can be applied by the customer to the test results, on request. It is not the responsibility or liability of STEYN-WILSON LABORATORIES (PTY) LTD.

DIRECTORS:	**Mr. J. Steyn ND-Civil (Managing) | Mr. R. Wilson B-Tech Civil (Operations)**
FINANCIAL MANAGER:	**Mr. D. Erasmus CA (SA)**
LABORATORY MANAGER:	**Mr. K. Booysen**
OPARATION MANAGER:	**Mr. J Brits**
GEOTECHNICAL MANAGER:	**Mr. F Coetzee**
QUALITY MANAGER:	**Mrs. M Steyn E-Com I Tech**

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Customer :	**Zutari**	Project :	Ebenhauser
	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	26.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

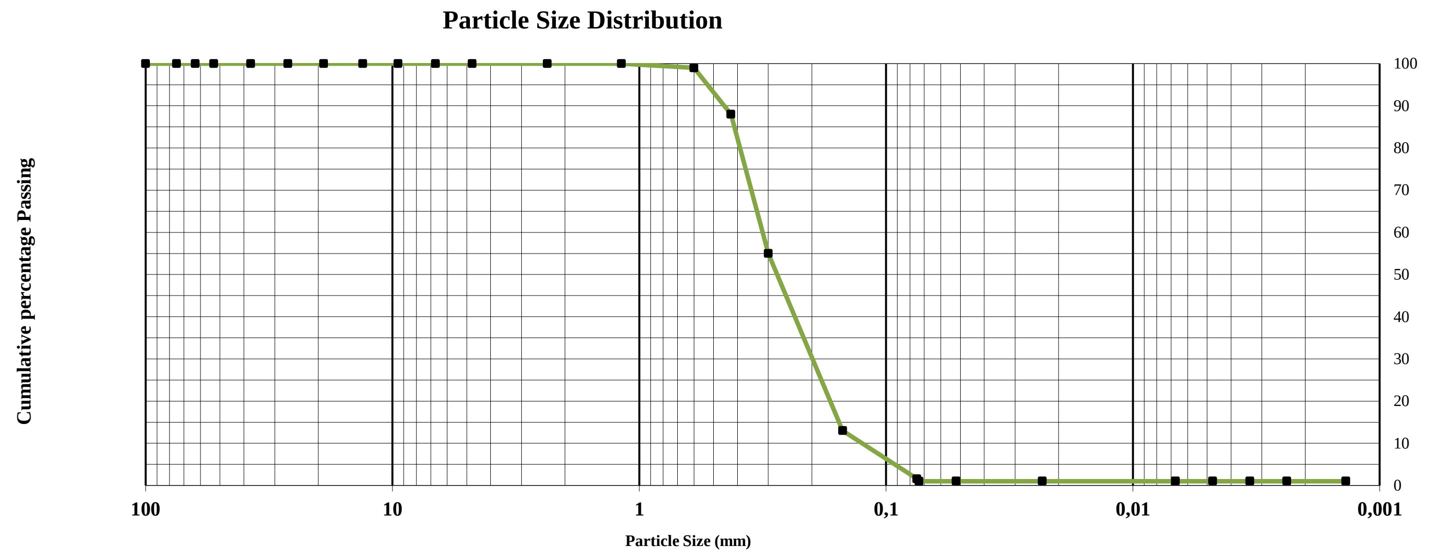
Material Description:	Dark Brown Reddish Sand	Sample Number:	13907		
Position:	TP17	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.0 - 1.7m	Plasticity Index	**NP**	Insitu M/C%	**2,5**

pH (TMH1 A20)*	**6,9**	**Conductivity s.m-¹ (TMH1 A21T)***	**0,002**	**COLTO SPEC**	

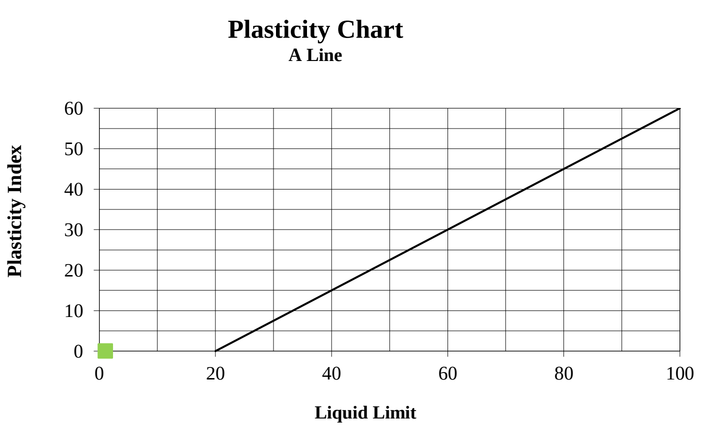
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	100	100	100	99	88	55	13	1,6	1	1	1	1	1	1	1	1

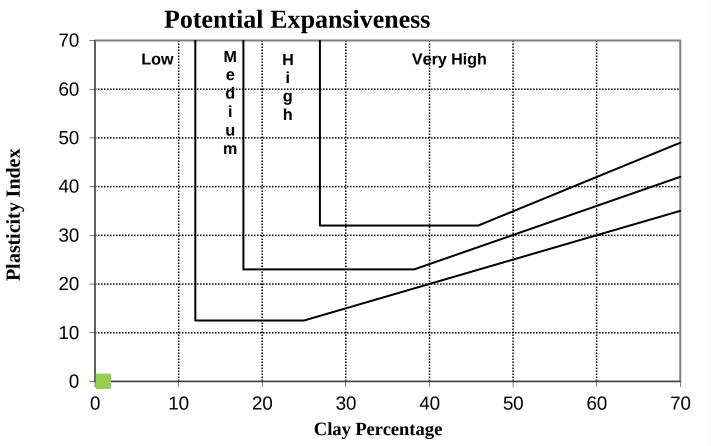
% Passing

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel		**% Sand**	**99**	**% Silt**		**% Clay**	**1**





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Customer :	**Zutari**	Project :	Ebenhauser
	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	26.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

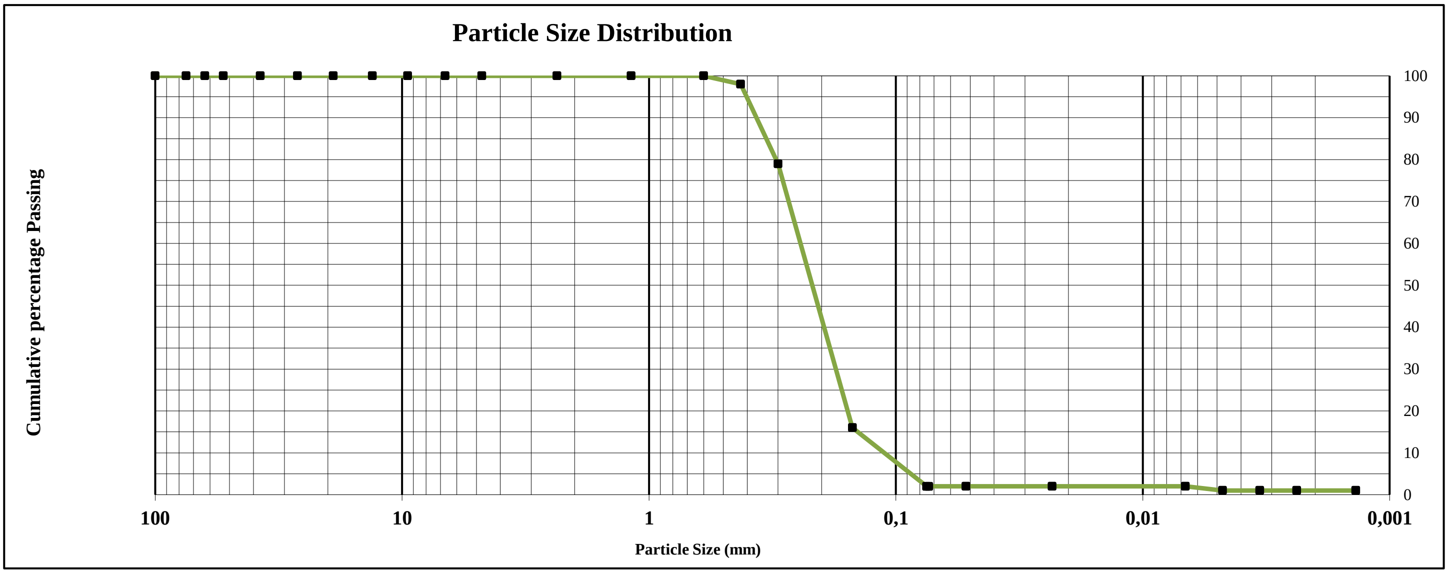
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Light Brown Orange Sand	Sample Number:	13954		
Position:	TP18	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.0 - 2.0m	Plasticity Index	**NP**	Insitu M/C%	**1,8**

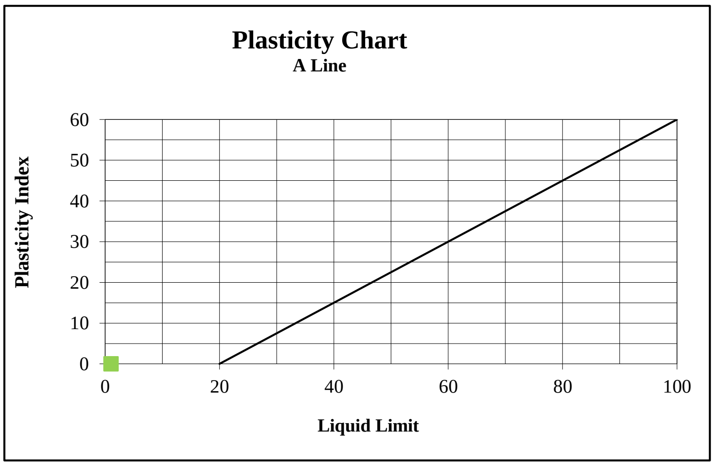
PH (TMH1 A20)*	**7,2**	**(TMH1 A21T)* Conductivity s.m^{-1}**	**0,016**	**COLTO SPEC**	

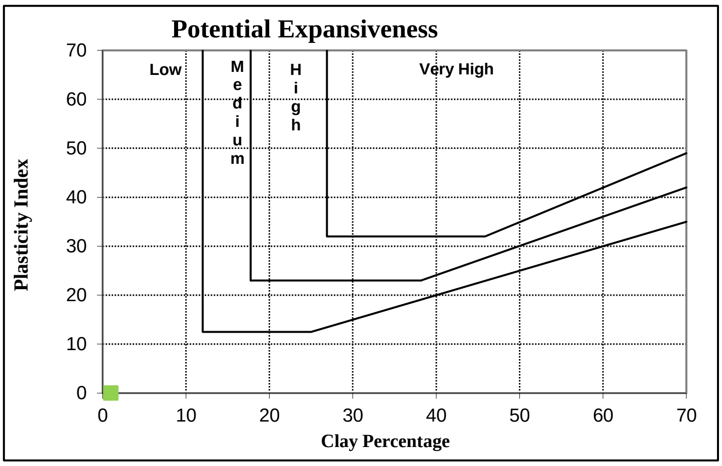
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	100	100	100	100	98	79	16	2	2	2	2	2	1	1	1	1
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel		**% Sand**	**98**	**% Silt**	**1**	**% Clay**	**1**





NOTE: All tests marked with (*) means that those test methods are not accredited.

Compiled by: M.Steyn

Approved By: J.Steyn

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CIVIL ENGINEERING TESTING LABORATORIES

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Email: admin@steynwilson.co.za
Web: www.steynwilson.co.za

Customer :	**Zutari**	Project :	Ebenhauser
	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	26.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

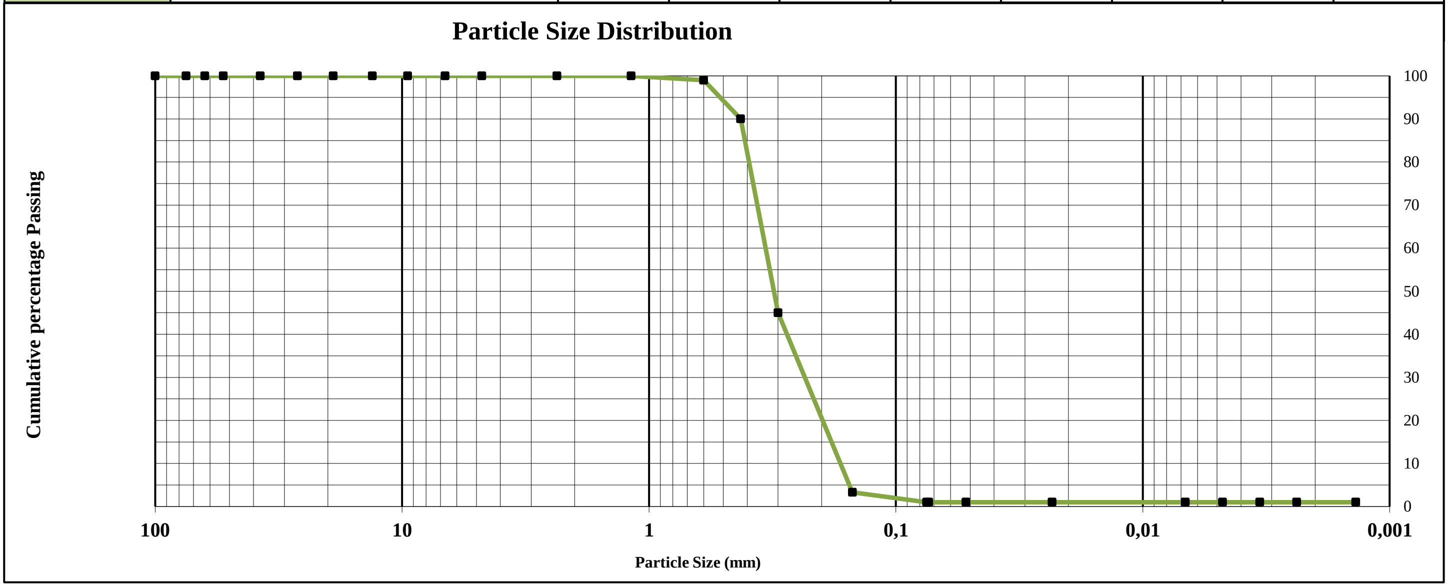
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Light Brown Reddish Fine Sand	Sample Number:	13946		
Position:	TP24 ADD	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.0 - 2.20m	Plasticity Index	**NP**	Insitu M/C%	**0,5**

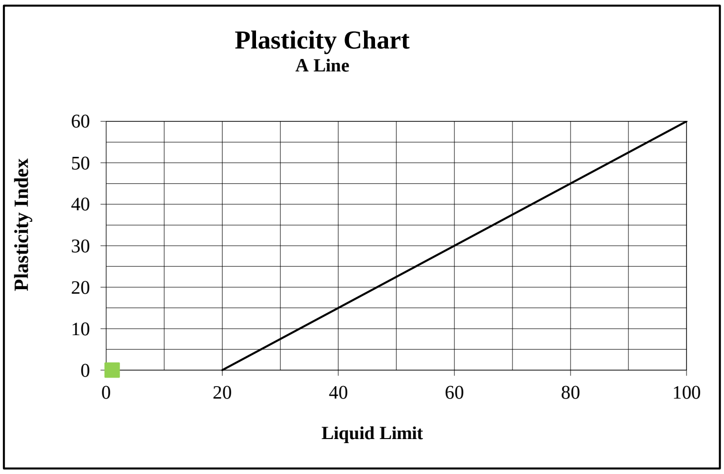
PH (TMH1 A20)*		**(TMH1 A21T)* Conductivity s.m^{-1}**		**COLTO SPEC**	**G9**

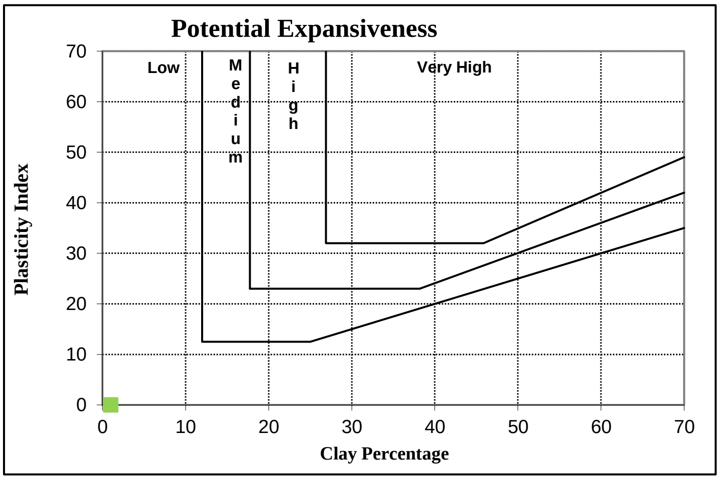
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	100	100	100	99	90	45	3,3	1	1	1	1	1	1	1	1	1
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%	10,4	**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)	1718	10,8	0,0	13	11	10	8	7	6



% Gravel		**% Sand**	99	**% Silt**		**% Clay**	1





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Customer :	**Zutari**	Project :	Ebenhauser
	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	26.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

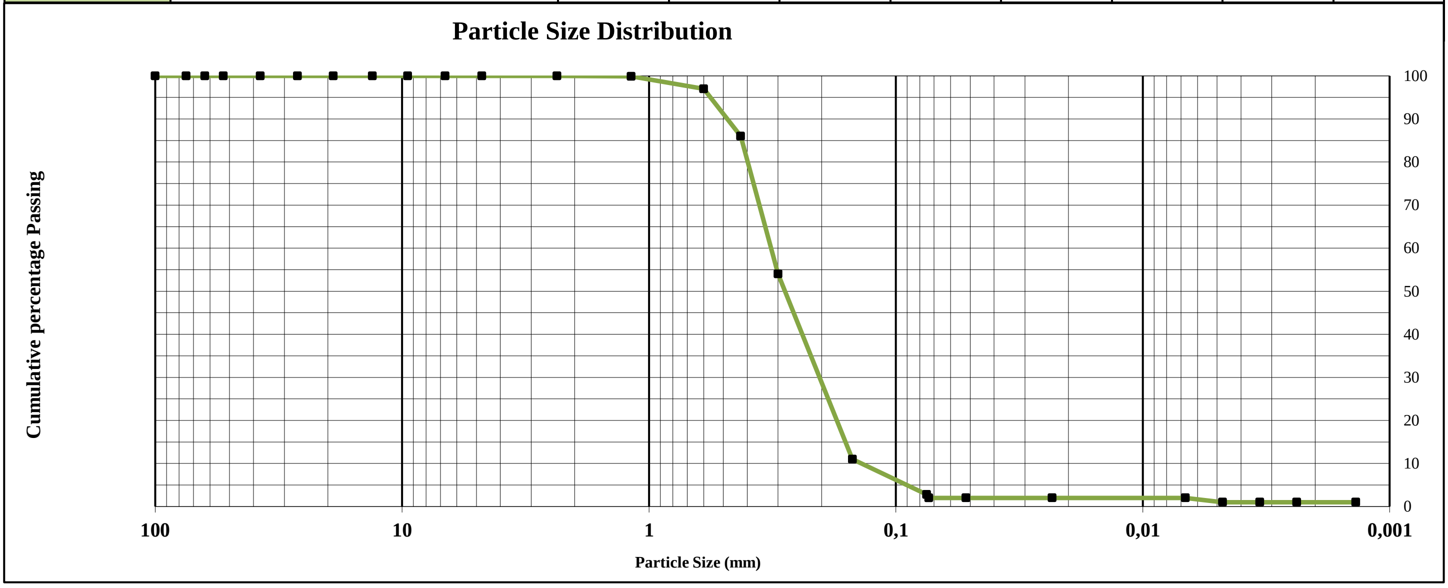
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Light Brown Reddish Sand	Sample Number:	13938		
Position:	TP28	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.0 - 2.5m	Plasticity Index	**NP**	Insitu M/C%	**1,2**

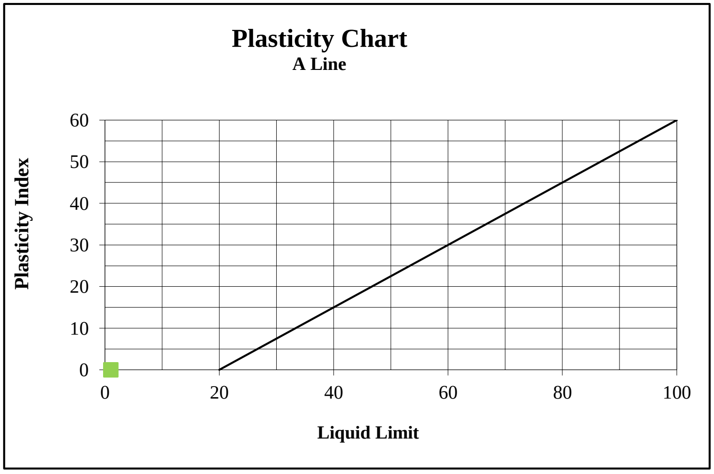
PH (TMH1 A20)*		**(TMH1 A21T)* Conductivity s.m^{-1}**		**COLTO SPEC**	**G9**

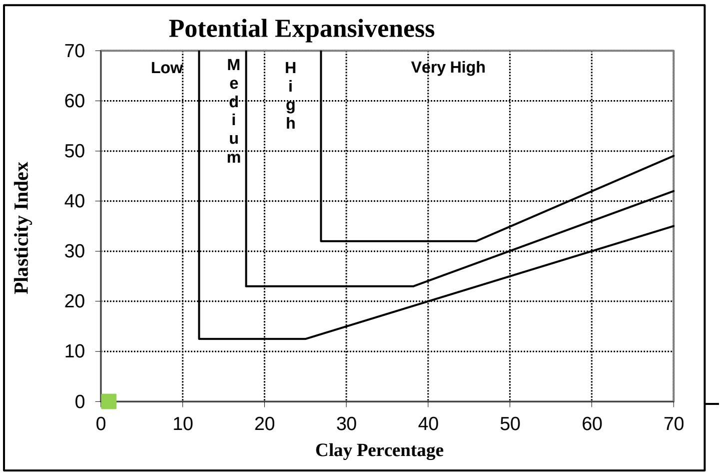
SIEVE ANALYSIS (TMH 1 A1a)*																		HYDROMETER ASTM D422							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	100	100	99,9	97	86	54	11	2,8	2	2	2	2	1	1	1	1
% Passing																									

MOD AASHTO SANS 3001 GR30		CBR SANS 3001 GR40							
OMC%	10,5	**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)	1821	10,1	0,0	12	11	10	9	8	7



% Gravel		**% Sand**	98	**% Silt**	1	**% Clay**	1





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Email: admin@steynwilson.co.za
Web: www.steynwilson.co.za

Client:	**Zutari**
Project:	Ebenhauser
Attention:	Ms K Myburgh
Your Ref. No:	113834
Date Reported	26.08.20

TEST REPORT REFERENCE NUMBER / JOB NUMBER : SWL12343

Dear Sir / Madam

Herewith please find the original reports pertaining to the above mentioned project.

Test Requested

3 x FOUNDATION INDICATORS
1 x MOD / CBR
2 x PH & CONDUCTIVITY

Site Sampling and Materials Information

Sampling Method	Specimens delivered to Steyn Wilson Laboratory.
Environmental Condition	Sunny
Deviation from the prescribed test method	
Responsibility of information disclaimer	

● **FINAL REPORT**

We would like to take this opportunity to thank you for your valued support.
Should you have any further enquiries please don't hesitate to contact me.

Yours Faithfully
STEYN-WILSON LABORATORIES (PTY) LTD

Mr. R.Wilson
Technical Signatory

Remarks:
1. Information contained herein is confidential to STEYN-WILSON PTY LTD and the addressee
2. Opinions & Interpretations are not included in our schedule of Accreditation.
3. The samples where subjected and analysed according to ASTM.
4. The results reported relate only to the sample tested, Further use of the attached information is not the responsibility or liability of STEYN-WILSON LABORATORIES (PTY) LTD.
5. This document is the correct record of all measurements made, and may not be reproduced other than with full written approval from a director of STEYN-WILSON LABORATORIES (PTY) LTD.
6. Measuring equipment is traceable to national standards (Where applicable).
7. Should there be any deviation from the prescribed test method comments will be made thereof, pertaining to the test on the relevant materials report.
8. Uncertainty of measurement is calculated and corresponds to a coverage probability of approximately 95%. Available on request.
9. The decision rule states that the measurement of uncertainty can be applied by the customer to the test results, on request. It is not the responsibility or liability of STEYN-WILSON LABORATORIES (PTY) LTD.

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Web: www.steynwilson.co.za

Customer : **Zutari**
1 Century City Drive
Century City
7446
Attention : Ms K Myburgh

Project : Ebenhauser
Date Received : 01.08.20
Date Reported : 26.08.20
Req. Number : 113834

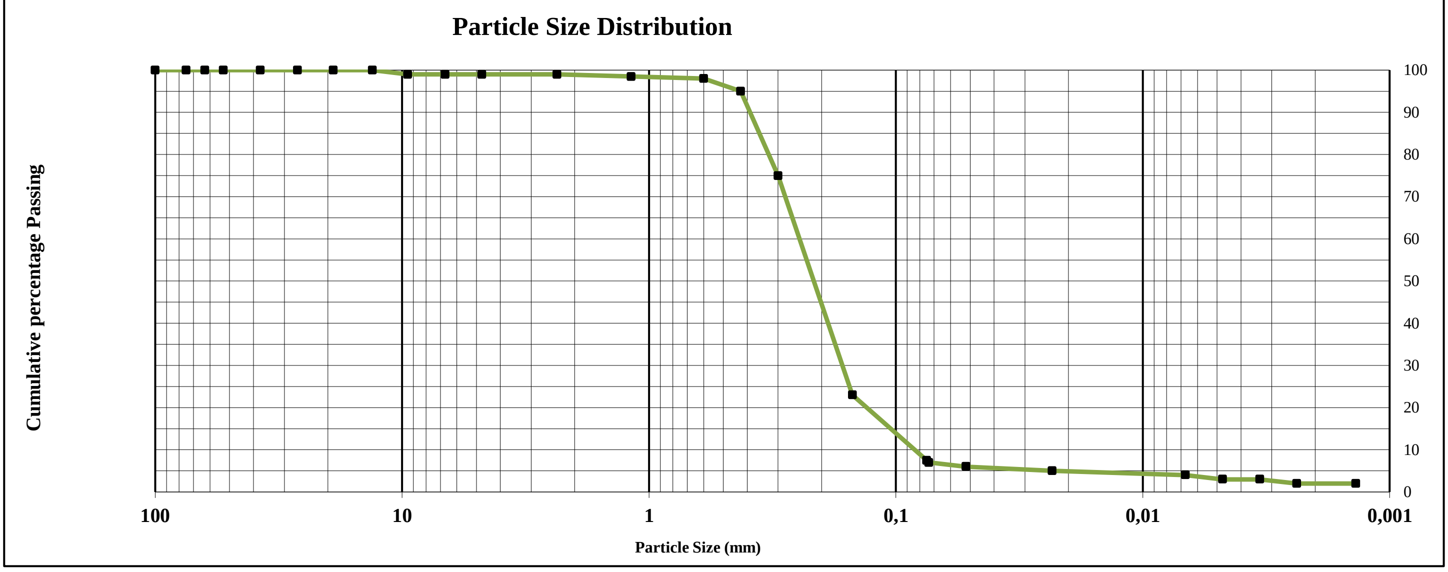
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Dark Brown Orange Soil	Sample Number:	13942		
Position:	TP33	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.0 - 1.60m	Plasticity Index	**NP**	Insitu M/C%	**6,5**

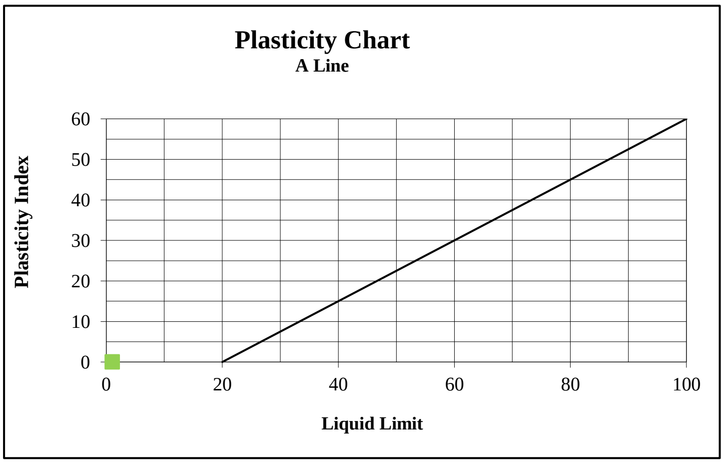
pH (TMH1 A20)*		**Conductivity** s.m-¹ **(TMH1 A21T)***		**COLTO SPEC**	**G9**

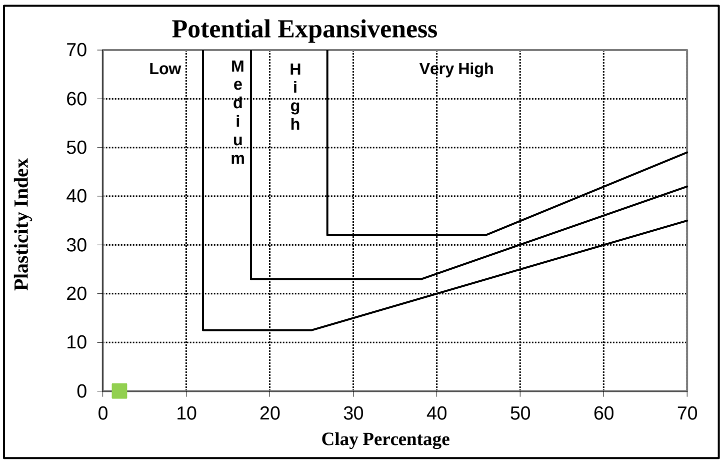
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	99	99	99	99	98,5	98	95	75	23	7,5	7	6	5	4	3	3	2	2
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%	11,3	**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)	1650	11,7	0,0	12	10	9	8	7	5



% Gravel	1	**% Sand**	93	**% Silt**	4	**% Clay**	2





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Customer :	**Zutari**	Project :	Ebenhauser
	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	26.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

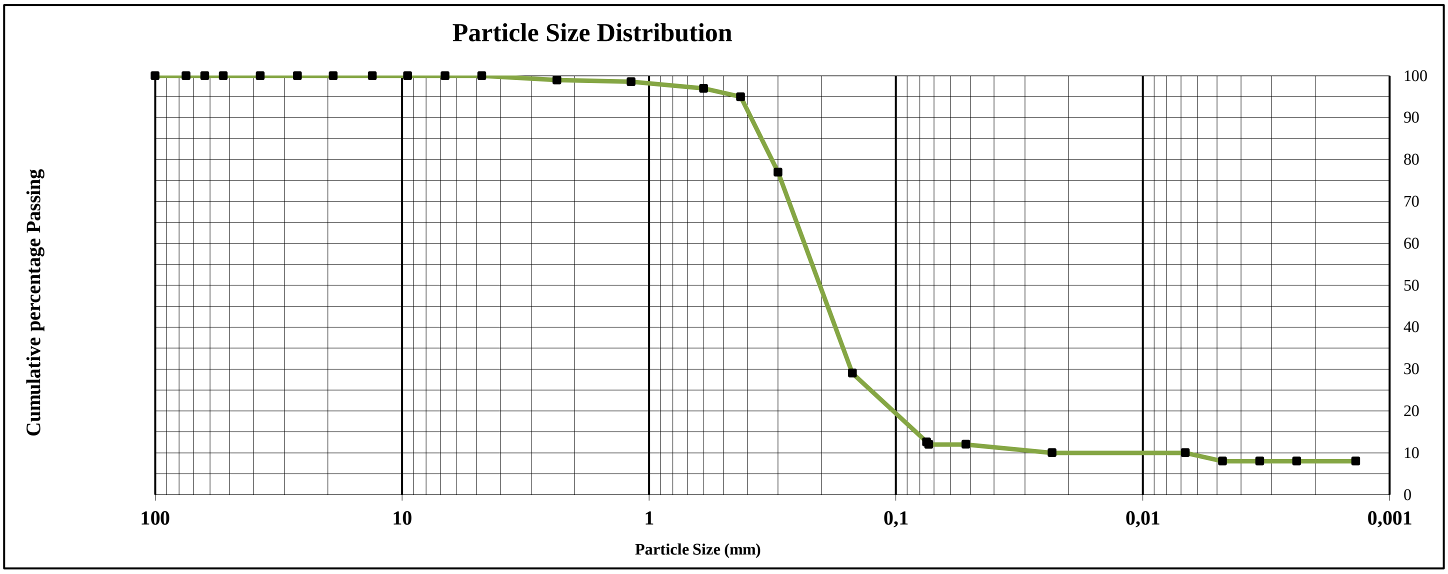
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Light Brown Reddish Orange Silty Soil	Sample Number:	13943		
Position:	TP33	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	1.3 - 1.6m	Plasticity Index	**NP**	Insitu M/C%	**1,8**

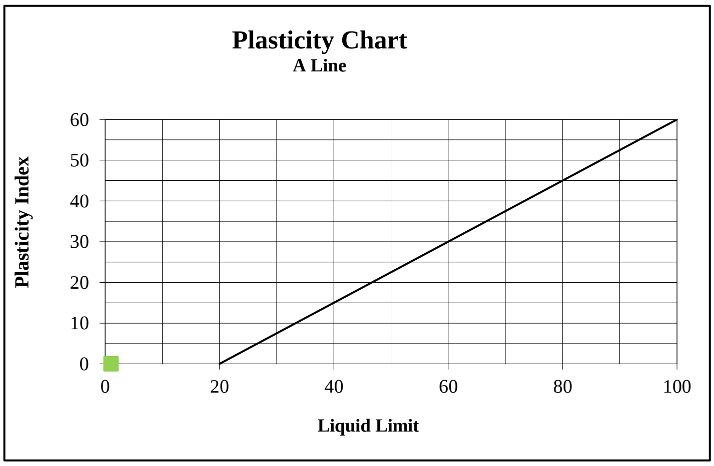
PH (TMH1 A20)*	**7,8**	**(TMH1 A21T)* Conductivity s.m^{-1}**	**0,030**	**COLTO SPEC**	

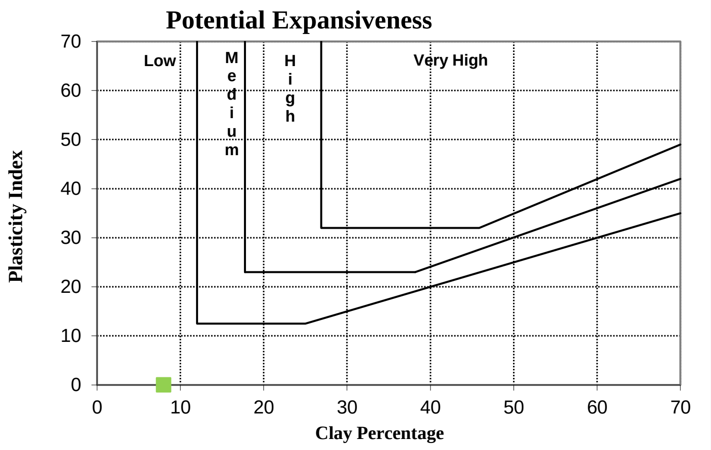
SIEVE ANALYSIS (TMH 1 A1a)*																		HYDROMETER ASTM D422							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	100	99	98,6	97	95	77	29	12,6	12	12	10	10	8	8	8	8
% Passing																									

MOD AASHTO SANS 3001 GR30		CBR SANS 3001 GR40							
OMC%		COMP MC	% SWELL	100%	98%	97%	95%	93%	90%
MDD(KG/M^3)									



% Gravel	**1**	**% Sand**	**87**	**% Silt**	**4**	**% Clay**	**8**





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Customer :	**Zutari**	Project :	Ebenhauser
	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	26.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

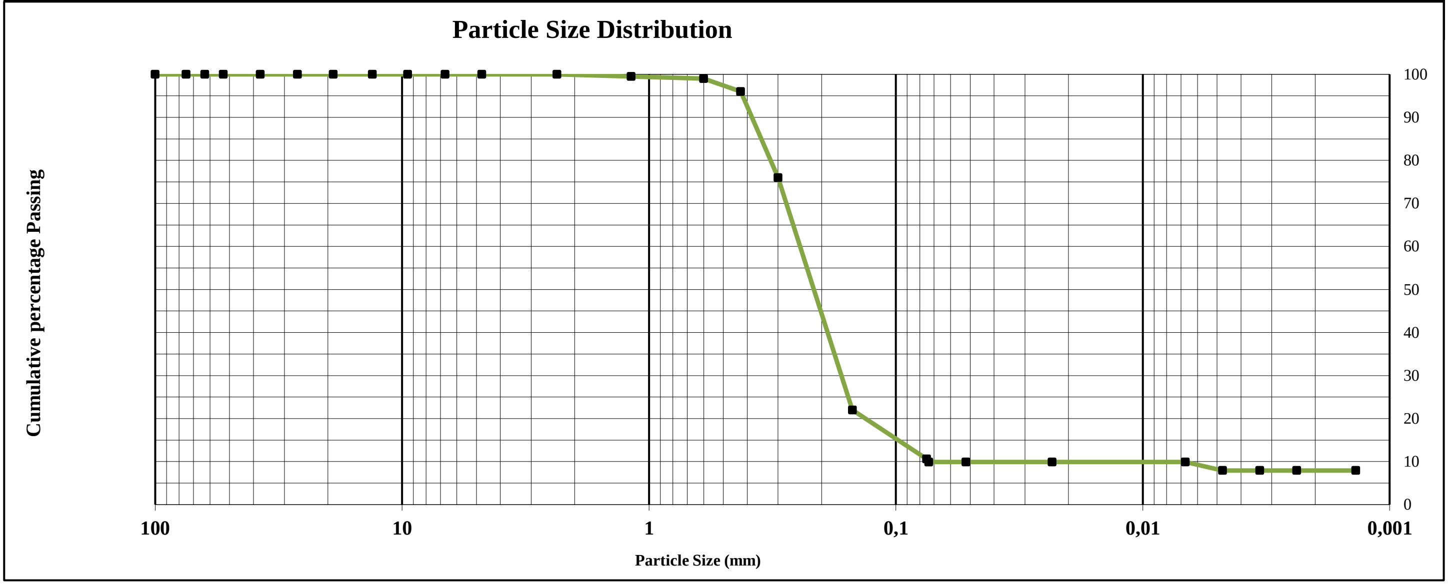
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Light Brown Reddish Orange Silty Soil	Sample Number:	13939		
Position:	TP35	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	1.20 - 1.50m	Plasticity Index	**NP**	Insitu M/C%	**6,5**

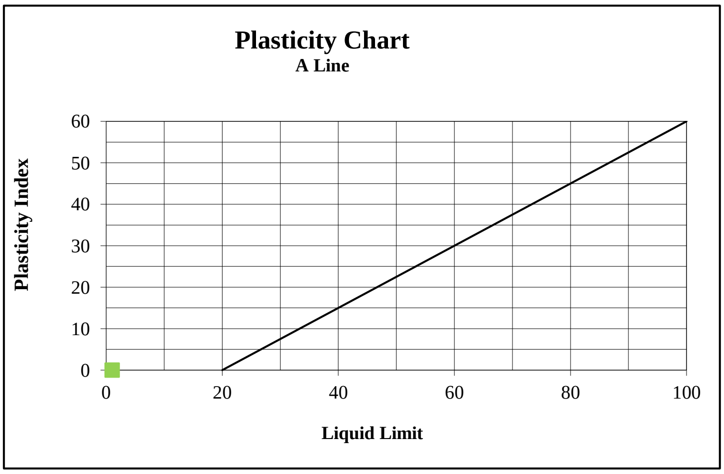
PH (TMH1 A20)*	**7,5**	**(TMH1 A21T)* Conductivity s.m^{-1}**	**0,136**	**COLTO SPEC**	

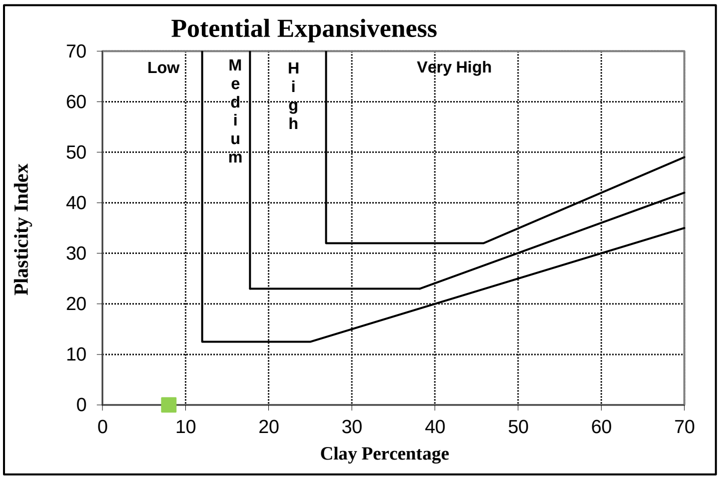
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	100	100	99,5	99	96	76	22	10,6	9,9	9,9	9,9	9,9	7,92	7,92	7,92	7,92
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel		**% Sand**	**90**	**% Silt**	**2**	**% Clay**	**8**





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Email: admin@steynwilson.co.za
Web: www.steynwilson.co.za

Client: **Zutari**
Project: Ebenhauzer
Attention: Ms K Myburgh
Your Ref. No: 113834
Date Reported 31.08.20

TEST REPORT REFERENCE NUMBER / JOB NUMBER : SWL12343

Dear Sir / Madam

Herewith please find the original reports pertaining to the above mentioned project.

Test Requested

4 x FOUNDATION INDICATORS
1 x MOD / CBR
2 x PH & CONDUCTIVITY

Site Sampling and Materials Information

Sampling Method	Specimens delivered to Steyn Wilson Laboratory.
Environmental Condition	Sunny
Deviation from the prescribed test method	
Responsibility of information disclaimer	

● **FINAL REPORT**

We would like to take this opportunity to thank you for your valued support.
Should you have any further enquiries please don't hesitate to contact me.

Yours Faithfully
STEYN-WILSON LABORATORIES (PTY) LTD

Mr. R.Wilson
Technical Signatory

Remarks:

1. Information contained herein is confidential to STEYN-WILSON PTY LTD and the addressee
2. Opinions & Interpretations are not included in our schedule of Accreditation.
3. The samples where subjected and analysed according to ASTM.
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9. The decision rule states that the measurement of uncertainty can be applied by the customer to the test results, on request. It is not the responsibility or liability of STEYN-WILSON LABORATORIES (PTY) LTD.

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Customer :	**Zutari**	Project :	Ebenhauzer
	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	31.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

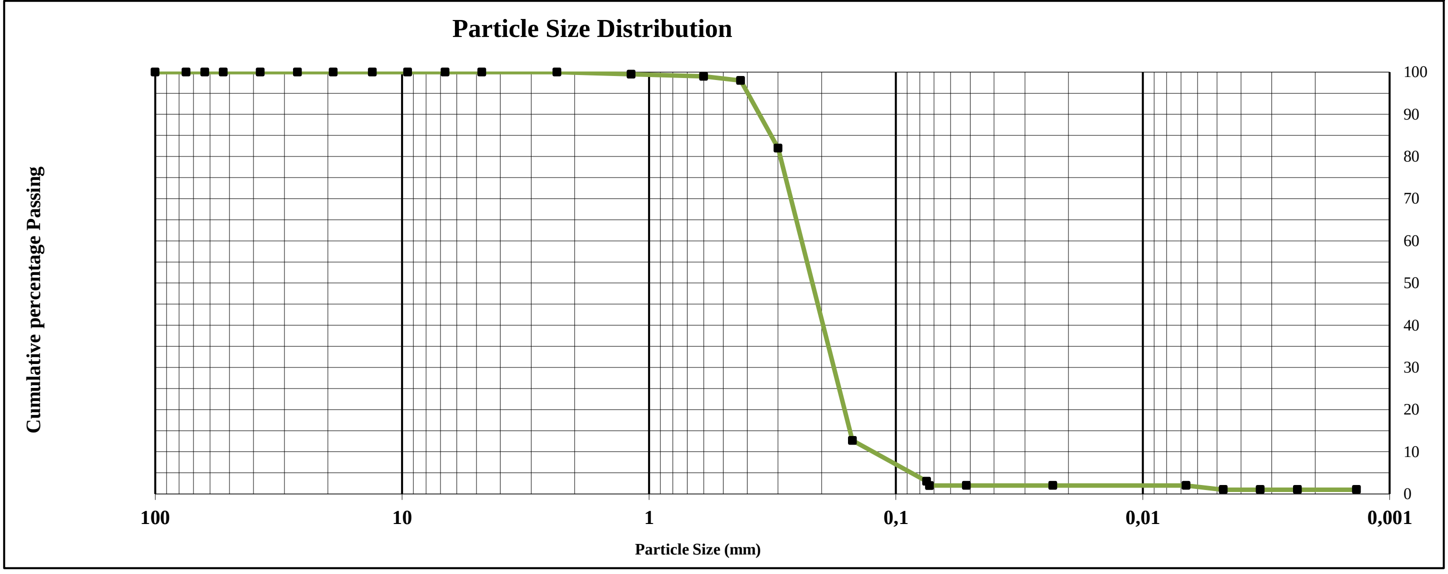
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Reddish Orange Sand	Sample Number:	13940		
Position:	TP38	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.00 - 0.90m	Plasticity Index	**NP**	Insitu M/C%	**2,2**

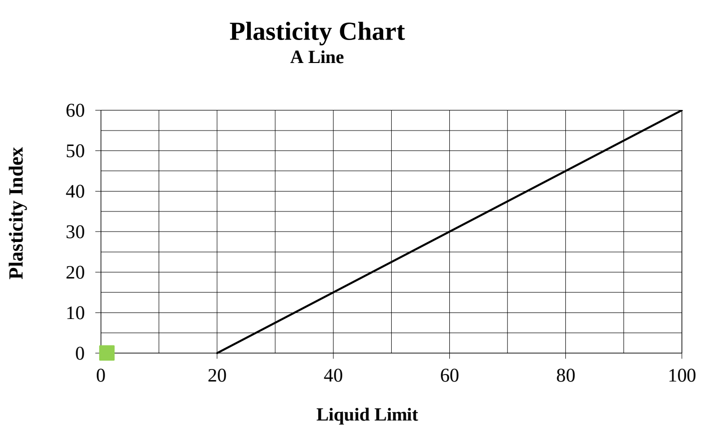
pH (TMH1 A20)*	**6,9**	**Conductivity s.m-¹ (TMH1 A21T)***	**0,024**	**COLTO SPEC**	**G9**

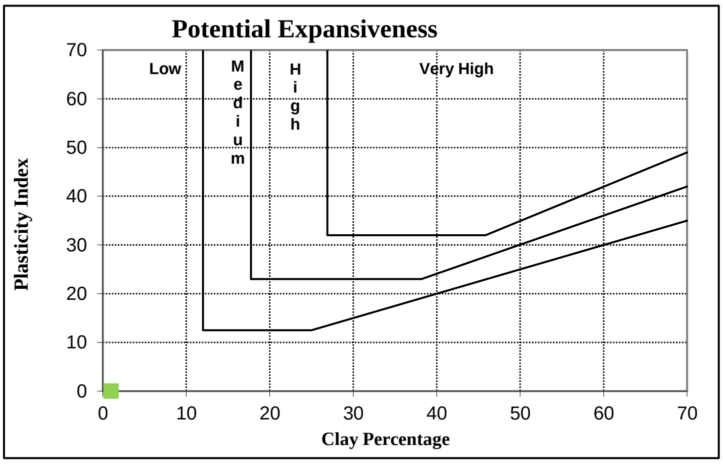
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,073	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	100	100	99,5	99	98	82	12,7	3	2	2	2	2	1	1	1	1
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%	11,2	**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)	1769	11,1	0,0	16	14	13	9	7	5



% Gravel		**% Sand**	**98**	**% Silt**	**1**	**% Clay**	**1**





NOTE: All tests marked with (*) means that those test methods are not accredited.

Compiled by: M.Steyn Approved By: J.Steyn

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Customer : **Zutari**
1 Century City Drive
Century City
7446
Attention : Ms K Myburgh

Project : Ebenhauzer
Date Received : 01.08.20
Date Reported : 31.08.20
Req. Number : 113834

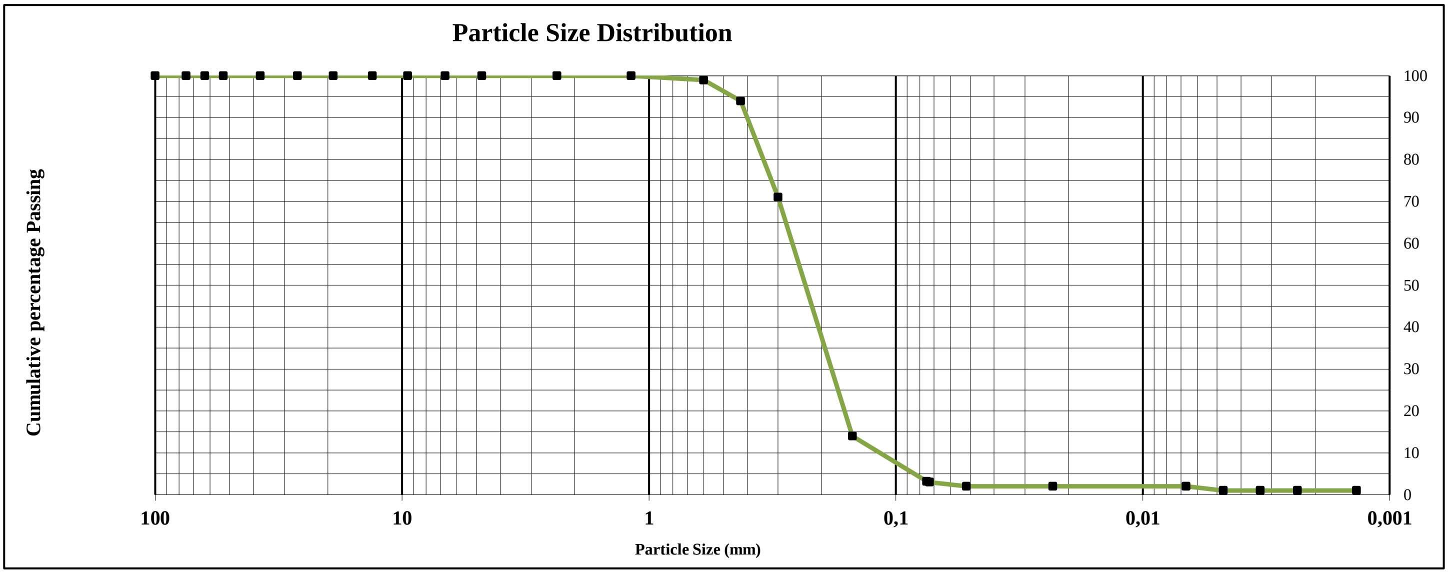
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Light Brown Reddish Sand	Sample Number:	13955		
Position:	TP40	Liquid Limit	**NP**	Linear Shrinkage	**0,0**
Depth:	1.1 - 2.5m	Plasticity Index	**NP**	Insitu M/C%	**1,3**

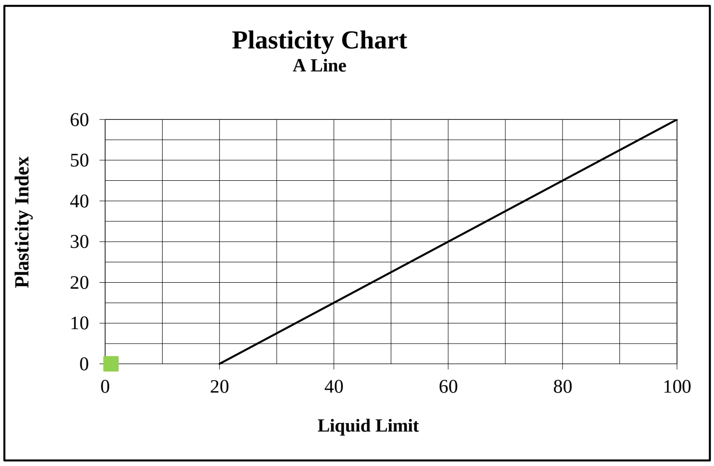
PH (TMH1 A20)*		**(TMH1 A21T)* Conductivity s.m^{-1}**		**COLTO SPEC**	

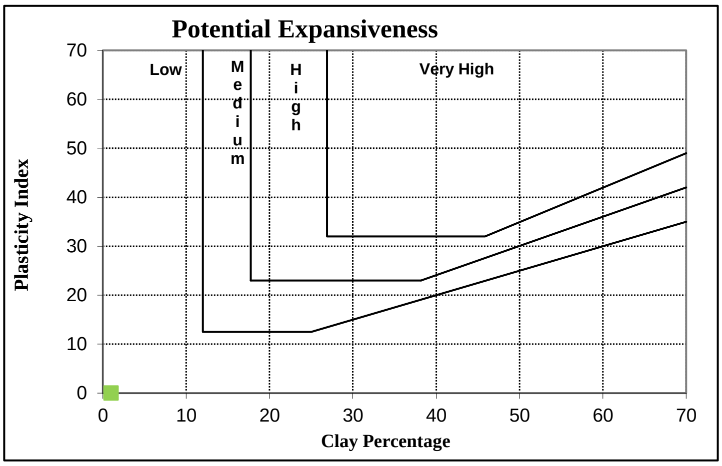
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**					
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,073	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	100	100	100	99	94	71	14	3,2	3	2	2	2	1	1	1	1
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel		**% Sand**	98	**% Silt**	1	**% Clay**	1





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CIVIL ENGINEERING TESTING LABORATORIES

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Fax: 086 499 9482
Email: admin@steynwilson.co.za
Web: www.steynwilson.co.za

Customer : **Zutari**
1 Century City Drive
Century City
7446
Attention : Ms K Myburgh

Project : Ebenhauzer
Date Received : 01.08.20
Date Reported : 31.08.20
Req. Number : 113834

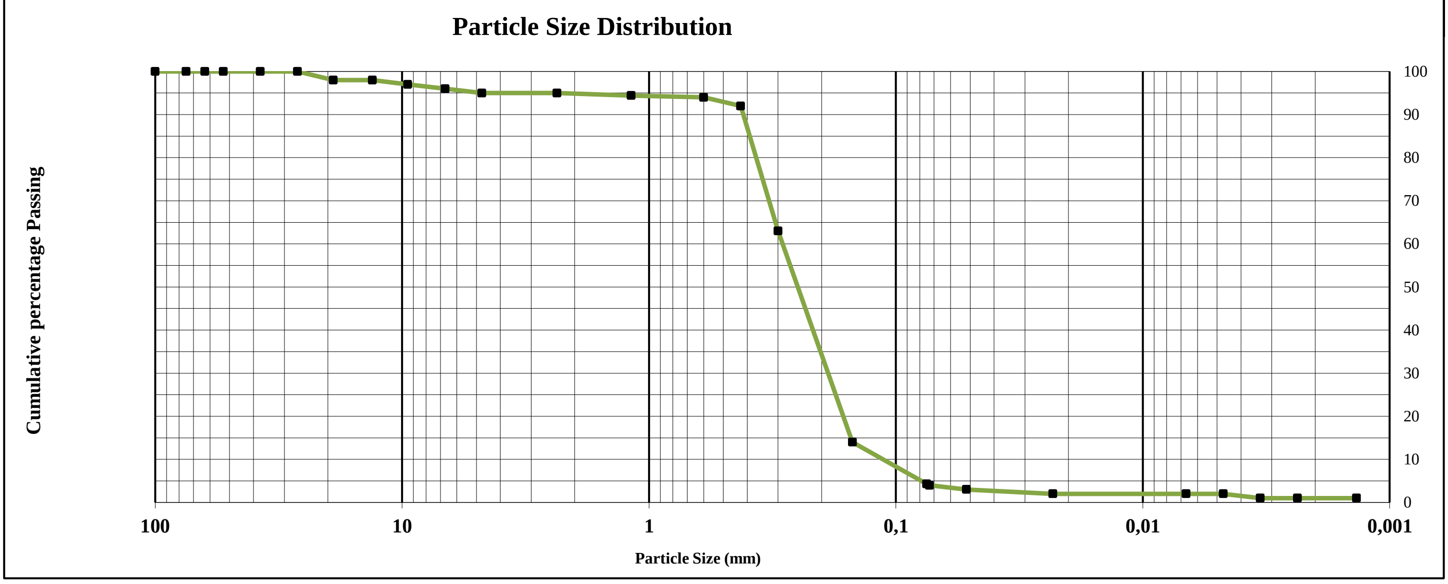
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Reddish Brown Orange Sand with Pebbles	Sample Number:	13941		
Position:	TP41	Liquid Limit	**NP**	Linear Shrinkage	**0,0**
Depth:	0.00 - 0.80m	Plasticity Index	**NP**	Insitu M/C%	**4,1**

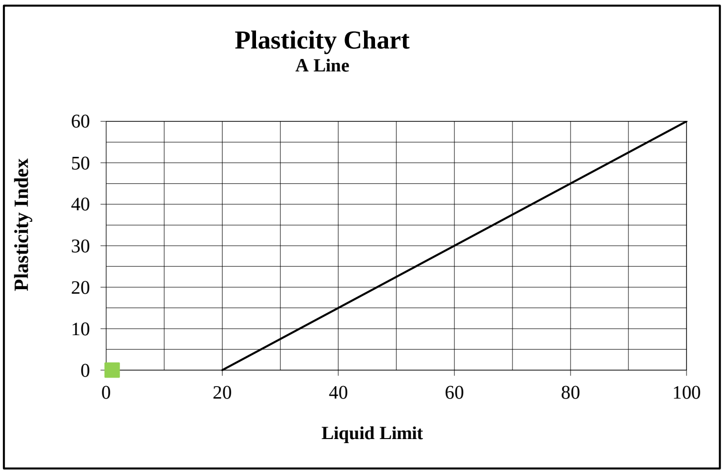
PH (TMH1 A20)*	**6,7**	**(TMH1 A21T)* Conductivity s.m^{-1}**	**0,015**	**COLTO SPEC**	

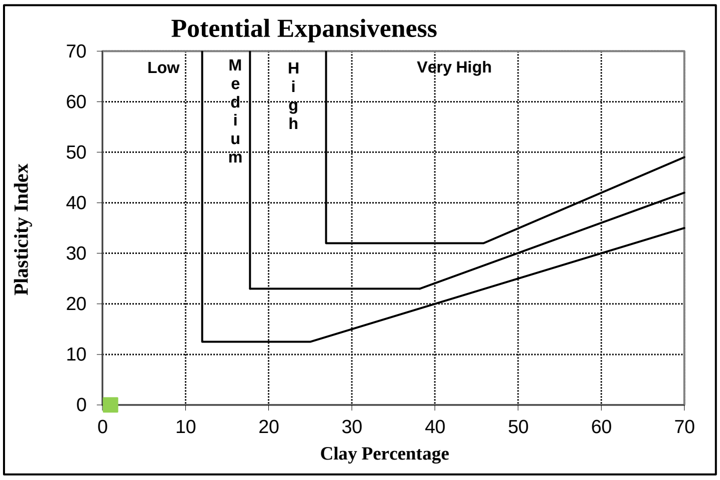
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,073	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	98	98	97	96	95	95	94,4	94	92	63	14	4,3	4	3	2	2	2	1	1	1
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel	5	**% Sand**	92	**% Silt**	2	**% Clay**	1





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Customer : **Zutari**
1 Century City Drive
Century City
7446
Attention : Ms K Myburgh

Project : Ebenhauzer
Date Received : 01.08.20
Date Reported : 31.08.20
Req. Number : 113834

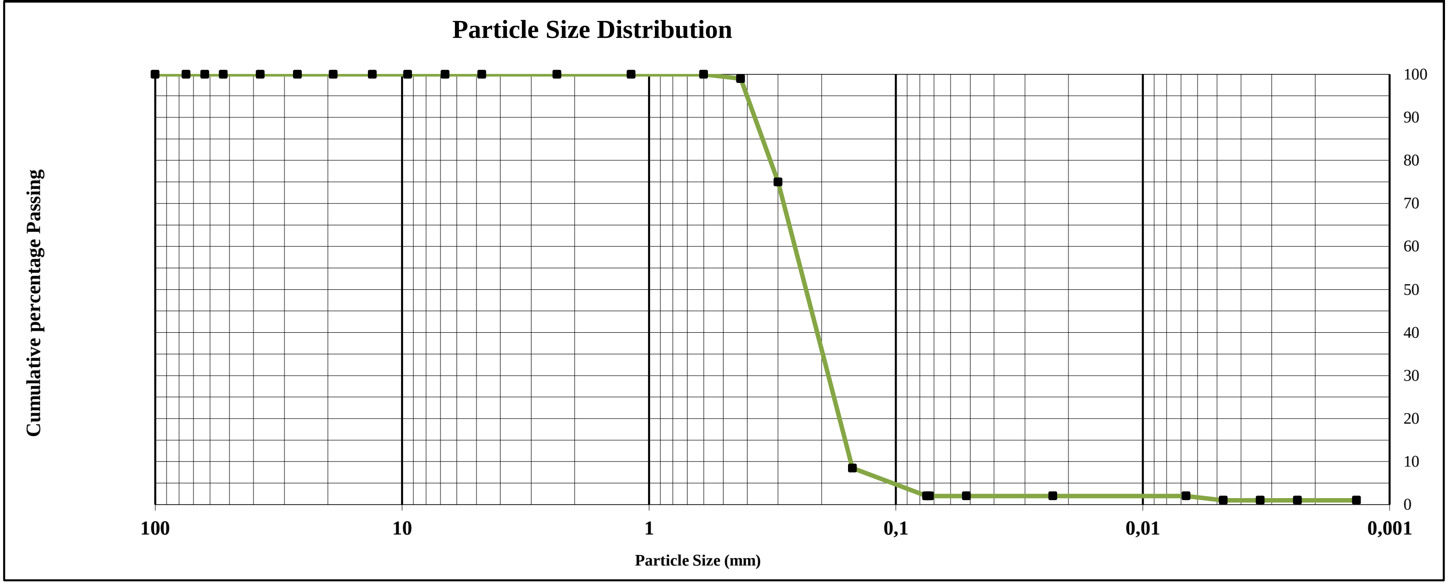
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Light Brown Reddish Orange Soil	Sample Number:	13924		
Position:	TP43	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.0 - 1.1m	Plasticity Index	**NP**	Insitu M/C%	**1,9**

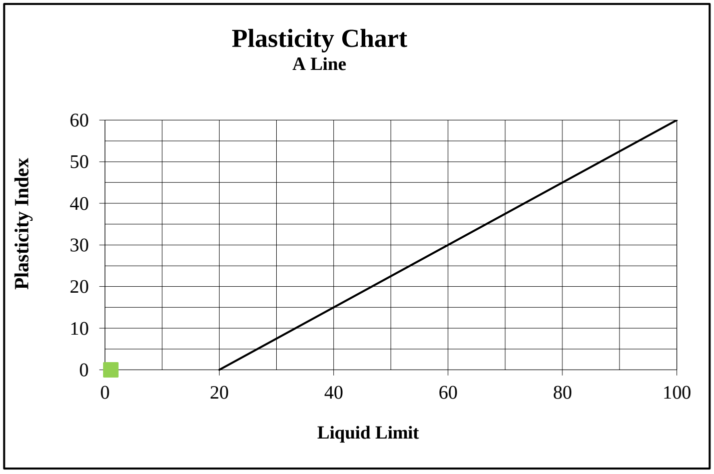
PH (TMH1 A20)*		**(TMH1 A21T)* Conductivity s.m^{-1}**		**COLTO SPEC**	

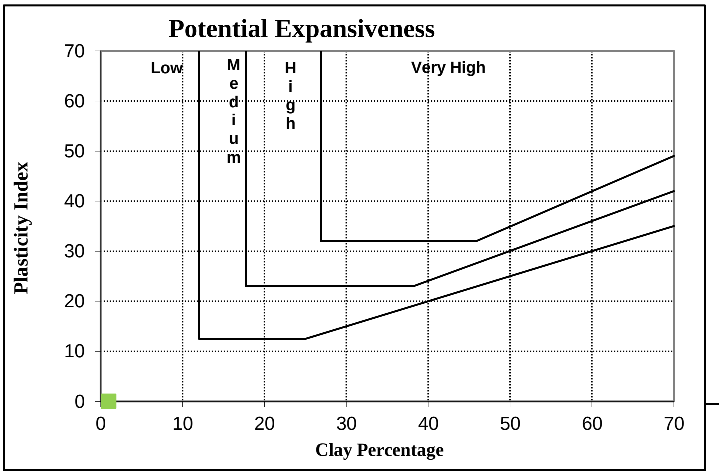
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,073	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	75	8,5	2	2	2	2	2	1	1	1	1
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel		**% Sand**	98	**% Silt**	1	**% Clay**	1





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Compiled by: M.Steyn Approved By: J.Steyn

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Web: www.steynwilson.co.za

Client:	**Zutari**
Project:	Ebenhauser
Attention:	Ms K Myburgh
Your Ref. No:	113834
Date Reported	31.08.20

TEST REPORT REFERENCE NUMBER / JOB NUMBER : SWL12343

Dear Sir / Madam

Herewith please find the original reports pertaining to the above mentioned project.

Test Requested

4	*x FOUNDATION INDICATORS*
2	*x MOD / CBR*
3	*x PH & CONDUCTIVITY*

Site Sampling and Materials Information

Sampling Method	Specimens delivered to Steyn Wilson Laboratory.
Environmental Condition	Sunny
Deviation from the prescribed test method	
Responsibility of information disclaimer	

● **FINAL REPORT**

We would like to take this opportunity to thank you for your valued support.
Should you have any further enquiries please don't hesitate to contact me.

Yours Faithfully
STEYN-WILSON LABORATORIES (PTY) LTD

Mr. R.Wilson
Technical Signatory

Remarks:

1. Information contained herein is confidential to STEYN-WILSON PTY LTD and the addressee
2. Opinions & Interpretations are not included in our schedule of Accreditation.
3. The samples where subjected and analysed according to ASTM.
4. The results reported relate only to the sample tested, Further use of the attached information is not the responsibility or liability of STEYN-WILSON LABORATORIES (PTY) LTD.
5. This document is the correct record of all measurements made, and may not be reproduced other than with full written approval from a director of STEYN-WILSON LABORATORIES (PTY) LTD.
6. Measuring equipment is traceable to national standards (Where applicable).
7. Should there be any deviation from the prescribed test method comments will be made thereof, pertaining to the test on the relevant materials report.
8. Uncertainty of measurement is calculated and corresponds to a coverage probability of approximately 95%. Available on request.
9. The decision rule states that the measurement of uncertainty can be applied by the customer to the test results, on request. It is not the responsibility or liability of STEYN-WILSON LABORATORIES (PTY) LTD.

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Customer : **Zutari**
1 Century City Drive
Century City
7446
Attention : Ms K Myburgh

Project : Ebenhauser
Date Received : 01.08.20
Date Reported : 31.08.20
Req. Number : 113834

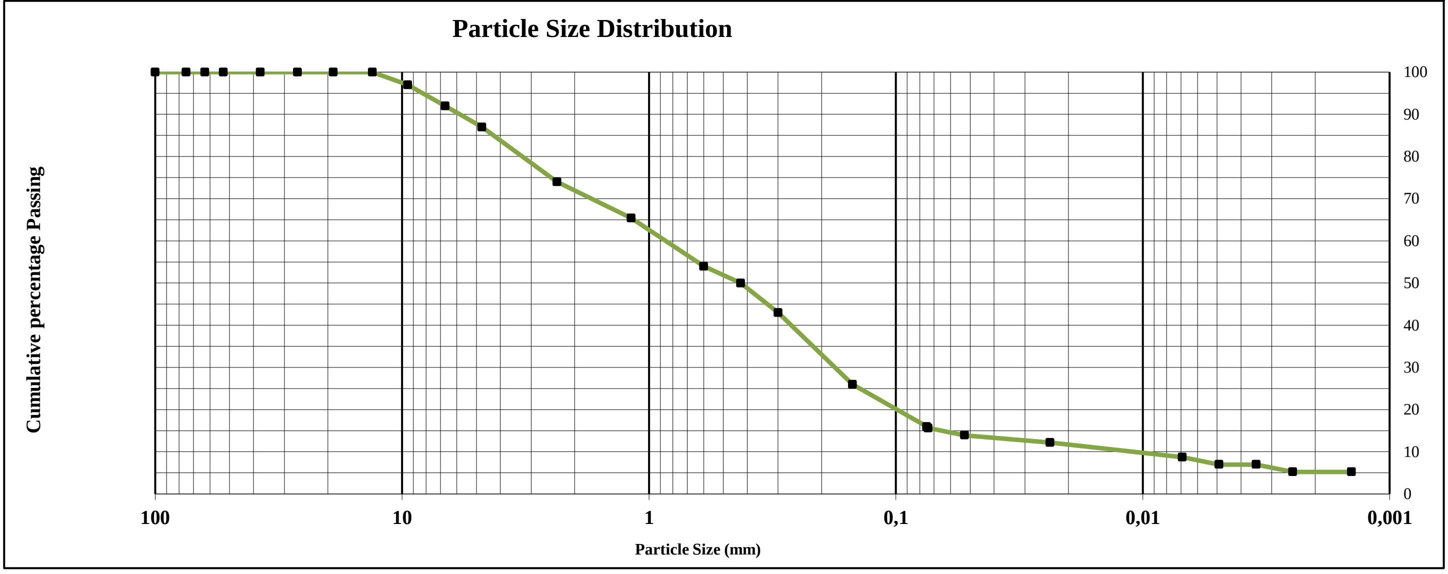
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Light Brown Olive Silty Soil with Calcrete	Sample Number:	13925		
Position:	TP45	Liquid Limit	**SP**	Linear Shrinkage	**1.2**
Depth:	0.5 - 1.1m	Plasticity Index	**SP**	Insitu M/C%	**8**

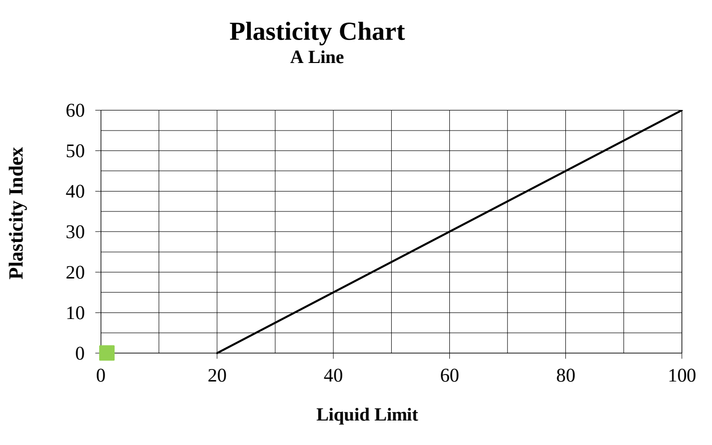
pH (TMH1 A20)*		**Conductivity s.m-1 (TMH1 A21T)***		**COLTO SPEC**	**G7**

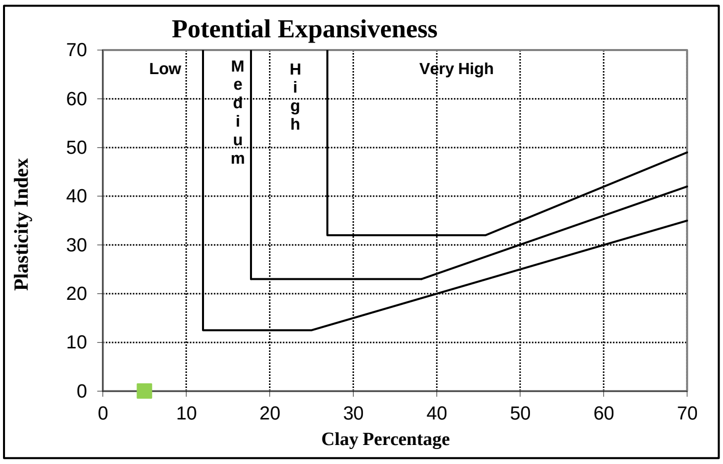
SIEVE ANALYSIS (TMH 1 A1a)*																		HYDROMETER ASTM D422							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,053	0,024	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	97	92	87	74	65,4	54	50	43	26	16	15,66	13,92	12,18	8,7	6,96	6,96	5,22	5,22
% Passing																									

MOD AASHTO SANS 3001 GR30		CBR SANS 3001 GR40							
OMC%	9,6	COMP MC	% SWELL	100%	98%	97%	95%	93%	90%
MDD(KG/M^3)	1912	10	0,0	27	22	20	17	15	12



% Gravel	29	% Sand	56	% Silt	10	% Clay	5





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Web: www.steynwilson.co.za

Customer :	**Zutari**	Project :	Ebenhauser
	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	31.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

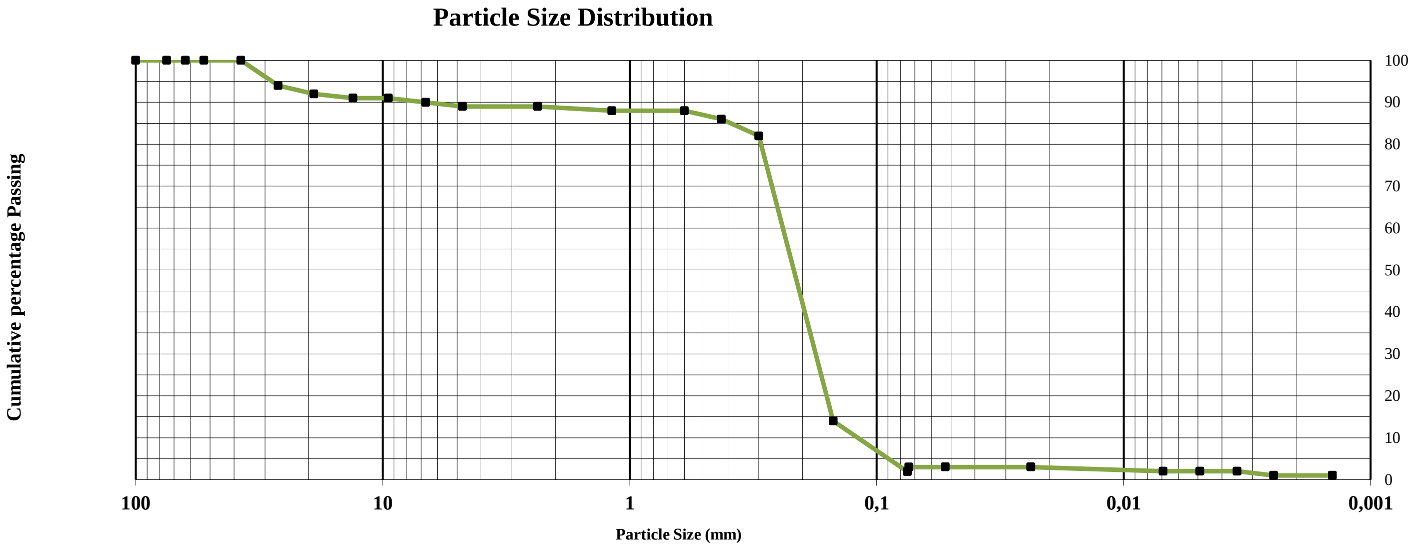
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Dark Brown Orange Soil	Sample Number:	13926		
Position:	TP46	Liquid Limit	**NP**	Linear Shrinkage	**0,0**
Depth:	0.0 - 0.6m	Plasticity Index	**NP**	Insitu M/C%	**4,6**

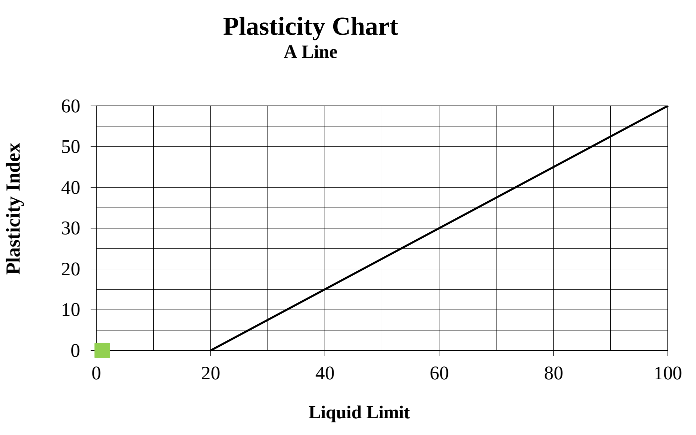
PH (TMH1 A20)*	**6,8**	**(TMH1 A21T)* Conductivity s.m^{-1}**	**0,025**	**COLTO SPEC**	**G8**

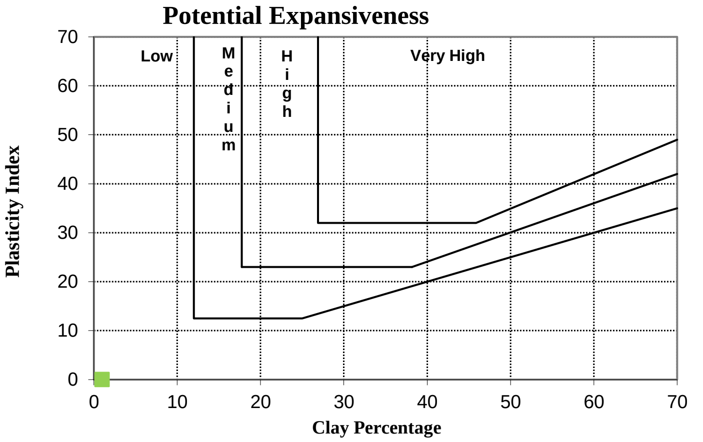
SIEVE ANALYSIS (TMH 1 A1a)*																**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,053	0,024	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	94	92	91	91	90	89	89	88	88	86	82	14	1,9	3	3	3	2	2	2	1	1
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%	9,5	**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)	1964	7	0,0	30	24	22	18	14	11



% Gravel	**11**	**% Sand**	**86**	**% Silt**	**2**	**% Clay**	**1**





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Customer :	**Zutari**	Project :	Ebenhauser
	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	31.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

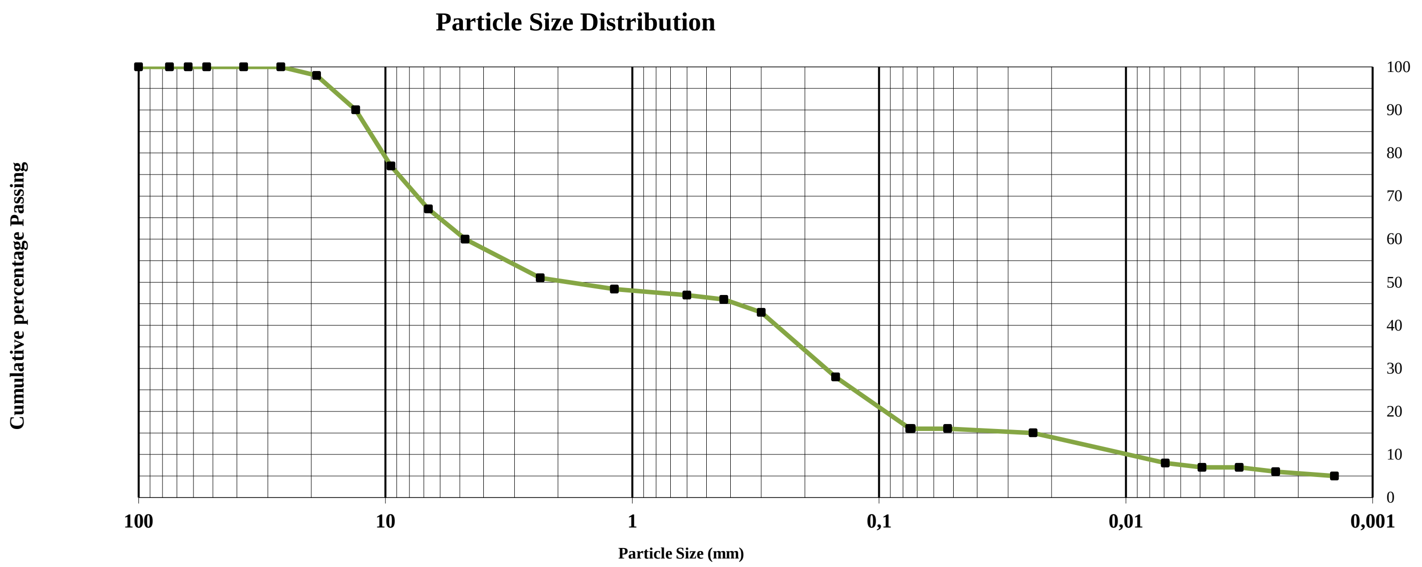
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Dark Brown Terrace Gravel	Sample Number:	13927		
Position:	TP46	Liquid Limit	**37**	Linear Shrinkage	**3,6**
Depth:	0.6 - 0.9m	Plasticity Index	**7,4**	Insitu M/C%	**1,1**

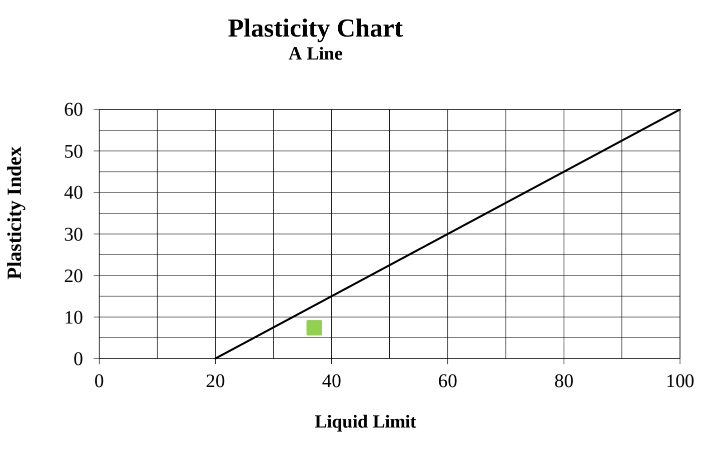
PH (TMH1 A20)*	**6,5**	**(TMH1 A21T)* Conductivity s.m^{-1}**	**0,183**	**COLTO SPEC**	

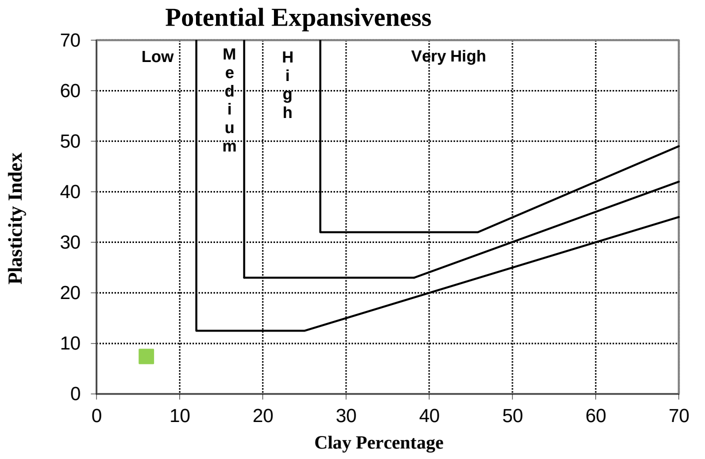
SIEVE ANALYSIS (TMH 1 A1a)*																**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,053	0,024	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	98	90	77	67	60	51	48,4	47	46	43	28	16	16	16	15	8	7	7	6	5
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel	50	% Sand	34	% Silt	10	% Clay	6





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7446
Attention : Ms K Myburgh

Project : Ebenhauser
Date Received : 01.08.20
Date Reported : 31.08.20
Req. Number : 113834

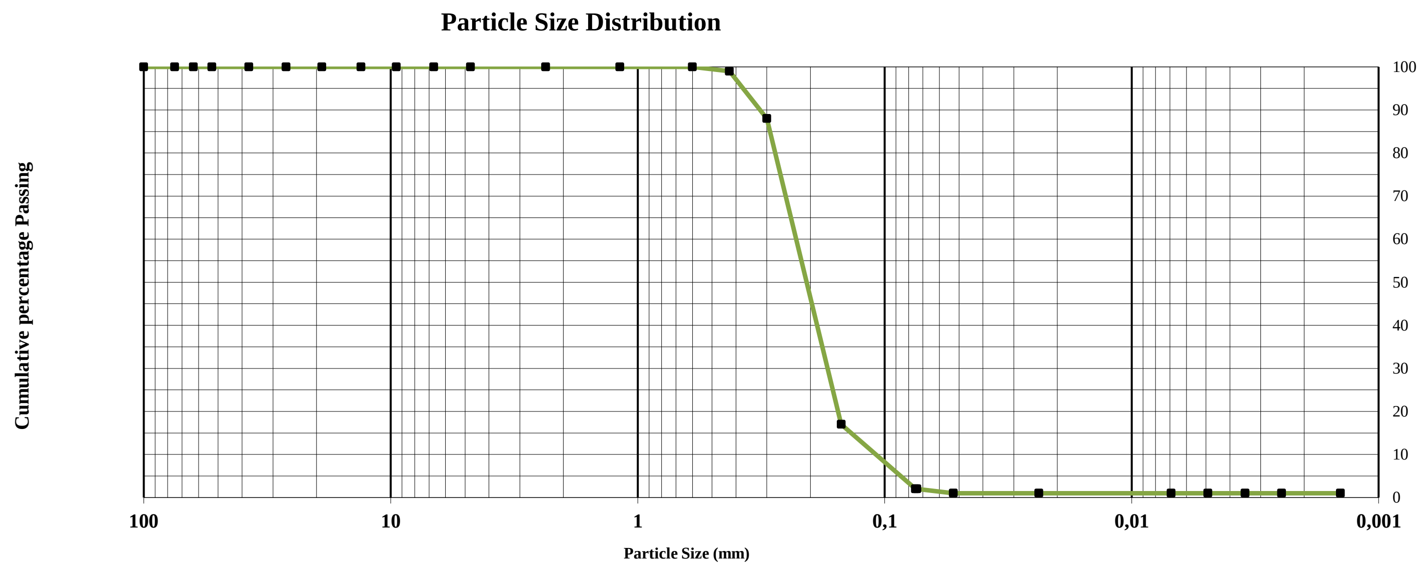
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Light Brown Reddish Fine Sand	Sample Number:	13928		
Position:	TP48	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.0 - 2.4m	Plasticity Index	**NP**	Insitu M/C%	**1,4**

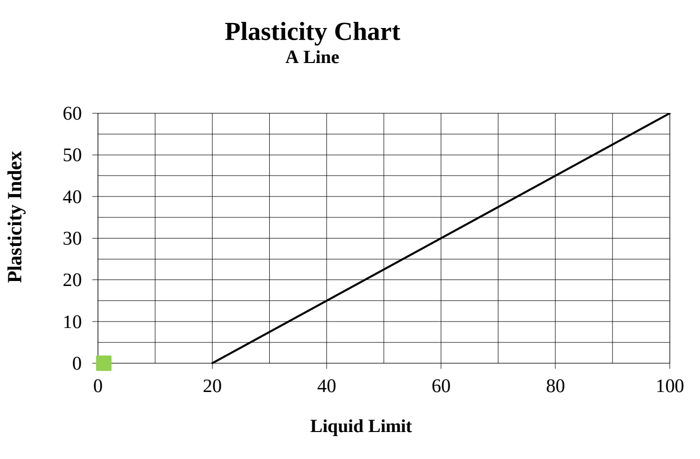
PH (TMH1 A20)*	**7,6**	**(TMH1 A21T)* Conductivity s.m^{-1}**	**0,007**	**COLTO SPEC**	

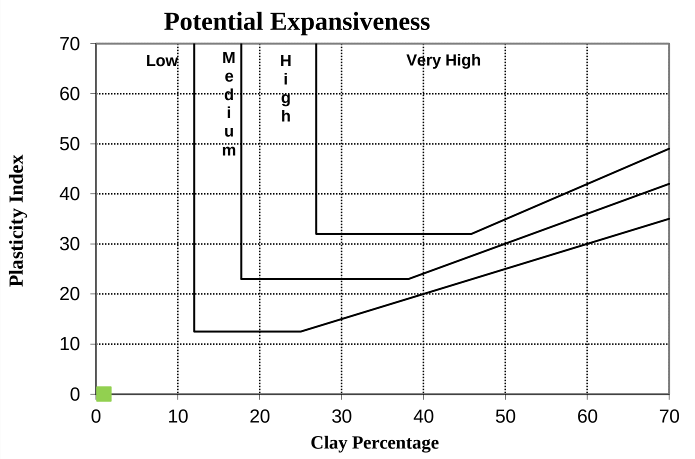
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,053	0,024	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	88	17	2	2	1	1	1	1	1	1	1
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel		**% Sand**	**99**	**% Silt**		**% Clay**	**1**





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Client:	**Zutari**
Project:	Ebenhauser
Attention:	Ms K Myburgh
Your Ref. No:	113834
Date Reported	31.08.20

TEST REPORT REFERENCE NUMBER / JOB NUMBER : SWL12343

Dear Sir / Madam

Herewith please find the original reports pertaining to the above mentioned project.

Test Requested

4 x FOUNDATION INDICATORS
2 x MOD / CBR
3 x PH & CONDUCTIVITY

Site Sampling and Materials Information

Sampling Method	Specimens delivered to Steyn Wilson Laboratory.
Environmental Condition	Sunny
Deviation from the prescribed test method	
Responsibility of information disclaimer	

● **FINAL REPORT**

We would like to take this opportunity to thank you for your valued support.
Should you have any further enquiries please don't hesitate to contact me.

Yours Faithfully
STEYN-WILSON LABORATORIES (PTY) LTD

Mr. R.Wilson
Technical Signatory

Remarks:
1. Information contained herein is confidential to STEYN-WILSON PTY LTD and the addressee
2. Opinions & Interpretations are not included in our schedule of Accreditation.
3. The samples where subjected and analysed according to ASTM.
4. The results reported relate only to the sample tested, Further use of the attached information is not the responsibility or liability of STEYN-WILSON LABORATORIES (PTY) LTD.
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8. Uncertainty of measurement is calculated and corresponds to a coverage probability of approximately 95%. Available on request.
9. The decision rule states that the measurement of uncertainty can be applied by the customer to the test results, on request. It is not the responsibility or liability of STEYN-WILSON LABORATORIES (PTY) LTD.

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	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	31.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

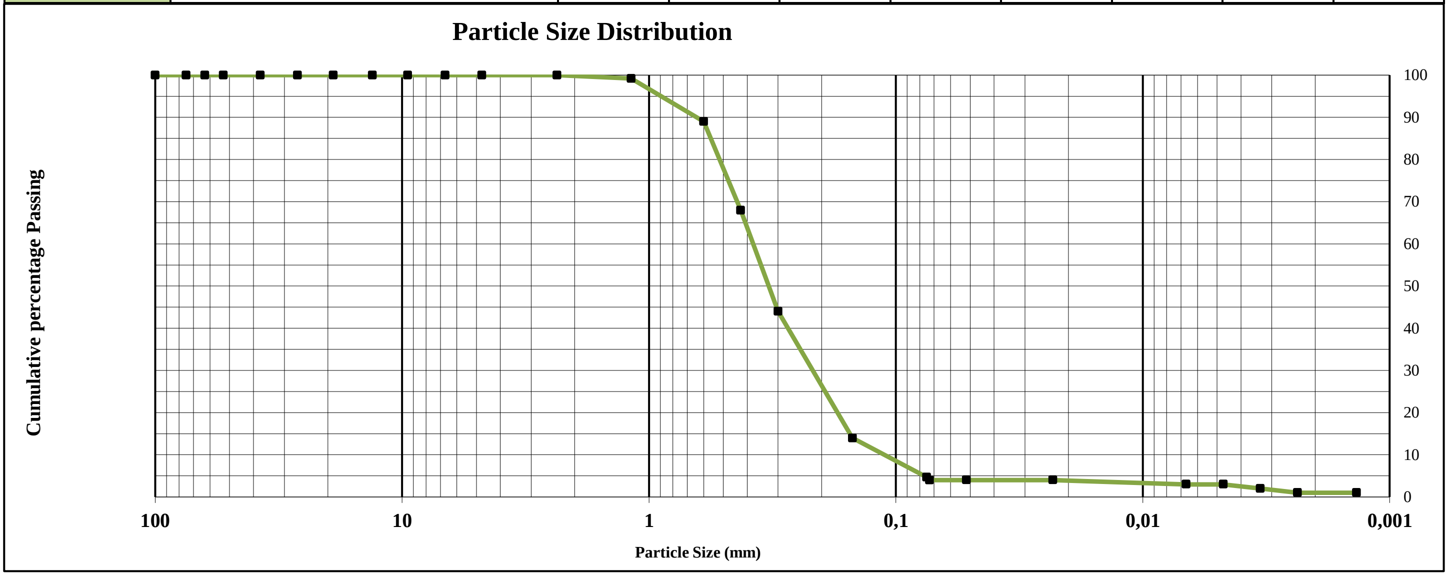
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Dark Brown Reddish Sand	Sample Number:	13929		
Position:	TP52	Liquid Limit	**NP**	Linear Shrinkage	**0,0**
Depth:	0.0 - 0.6m	Plasticity Index	**NP**	Insitu M/C%	**3,2**

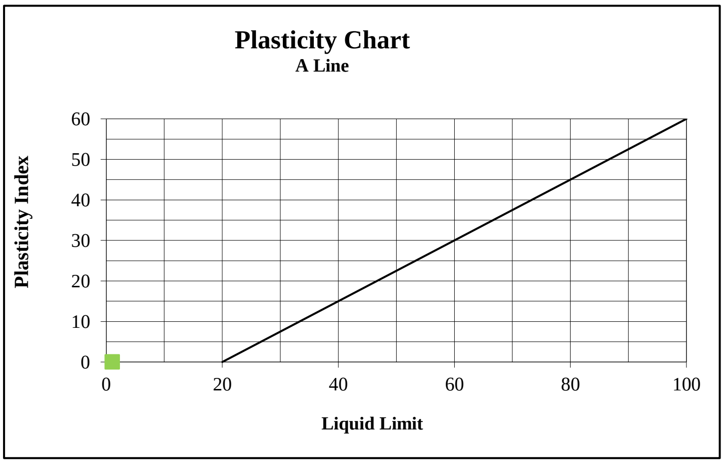
pH (TMH1 A20)*		**Conductivity** s.m-¹ **(TMH1 A21T)***		**COLTO SPEC**	

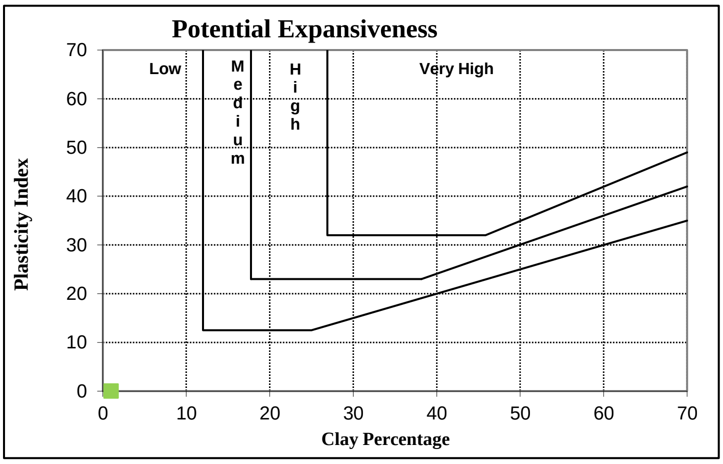
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,073	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	100	100	99,2	89	68	44	14	4,7	4	4	4	3	3	2	1	1
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel		**% Sand**	**96**	**% Silt**	**3**	**% Clay**	**1**





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Email: admin@steynwilson.co.za
Web: www.steynwilson.co.za

Customer : **Zutari**
1 Century City Drive
Century City
7446
Attention : Ms K Myburgh

Project : Ebenhauser
Date Received : 01.08.20
Date Reported : 31.08.20
Req. Number : 113834

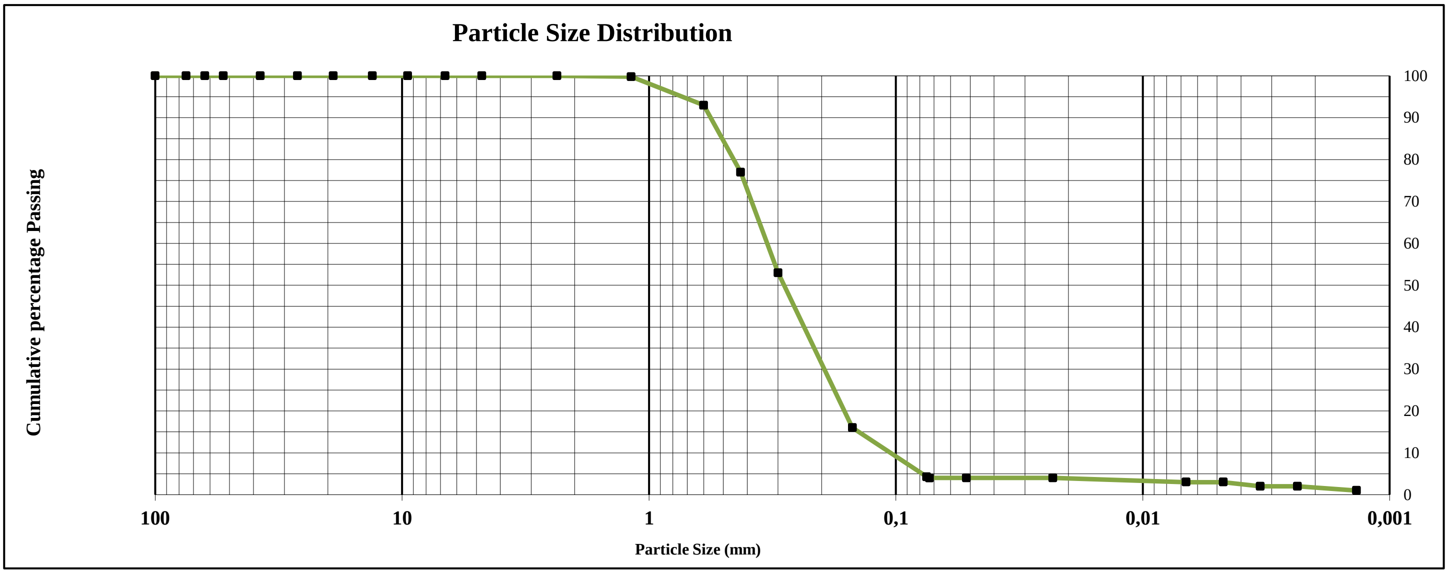
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Reddish Brown Sand	Sample Number:	13930		
Position:	TP53	Liquid Limit	**NP**	Linear Shrinkage	**0,0**
Depth:	0.0 - 1.5m	Plasticity Index	**NP**	Insitu M/C%	**1,6**

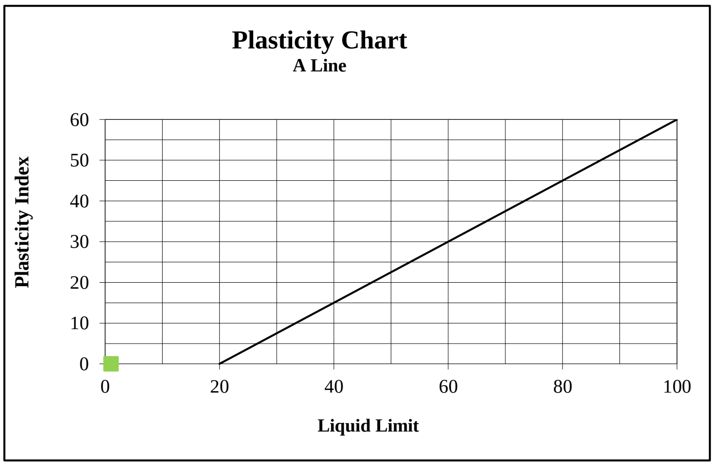
PH (TMH1 A20)*	**7,3**	**(TMH1 A21T)* Conductivity s.m^{-1}**	**0,028**	**COLTO SPEC**	**G10**

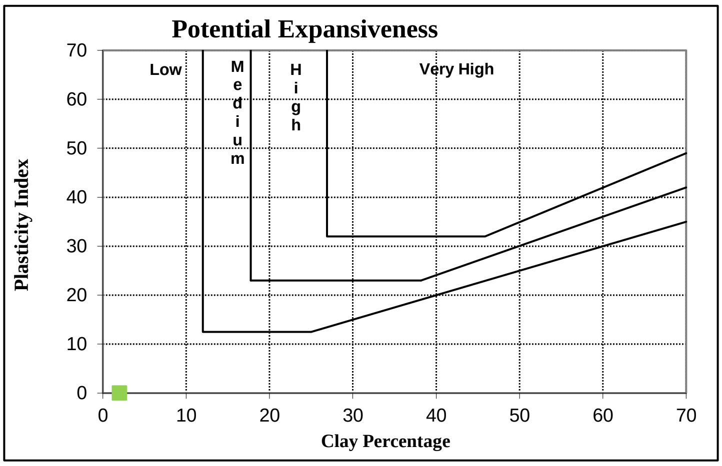
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,073	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	100	100	99,8	93	77	53	16	4,3	4	4	4	3	3	2	2	1
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%	11,1	**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)	1771	11,5	0,0	13	9	8	6	5	3



% Gravel		**% Sand**	**96**	**% Silt**	**2**	**% Clay**	**2**





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Customer :	**Zutari**	Project :	Ebenhauser
	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	31.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

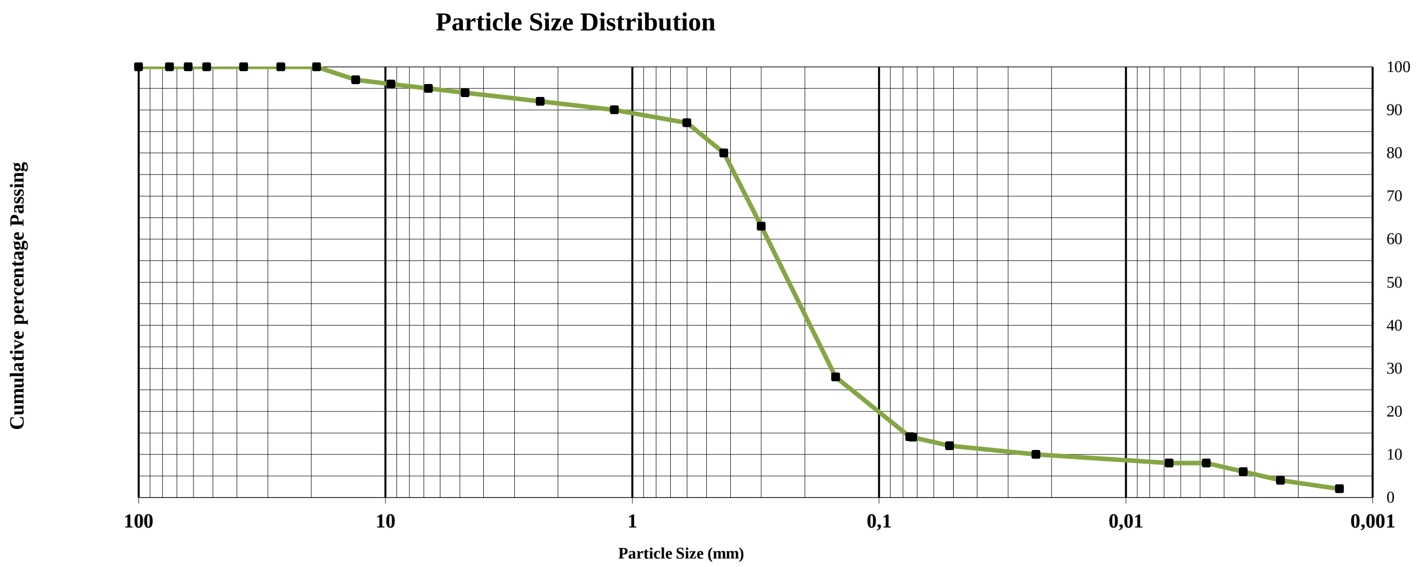
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Reddish Olive Soil with Calcrete	Sample Number:	13931		
Position:	TP57	Liquid Limit	**NP**	Linear Shrinkage	**0,0**
Depth:	0.5 - 1.9m	Plasticity Index	**NP**	Insitu M/C%	**6,3**

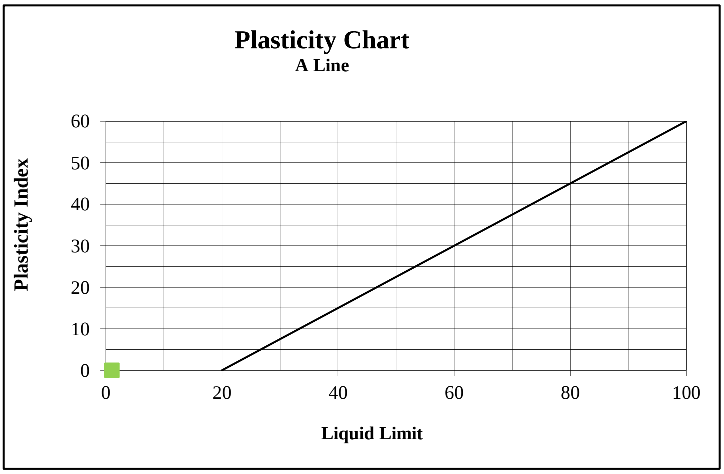
PH (TMH1 A20)*	**8,8**	**(TMH1 A21T)* Conductivity s.m^{-1}**	**0,407**	**COLTO SPEC**	**G8**

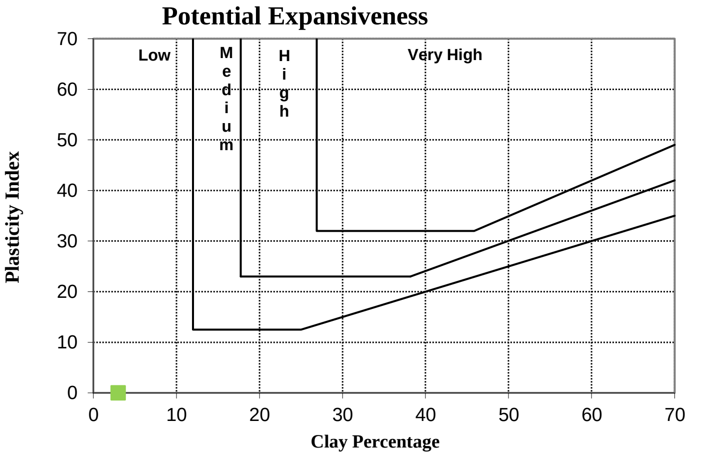
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,073	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	97	96	95	94	92	90	87	80	63	28	14,1	14	12	10	8	8	6	4	2
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%	9,6	**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)	2014	9,2	0,0	27	22	20	16	13	9



% Gravel	**9**	**% Sand**	**78**	**% Silt**	**10**	**% Clay**	**3**





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7446
Attention : Ms K Myburgh

Project : Ebenhauser
Date Received : 01.08.20
Date Reported : 31.08.20
Req. Number : 113834

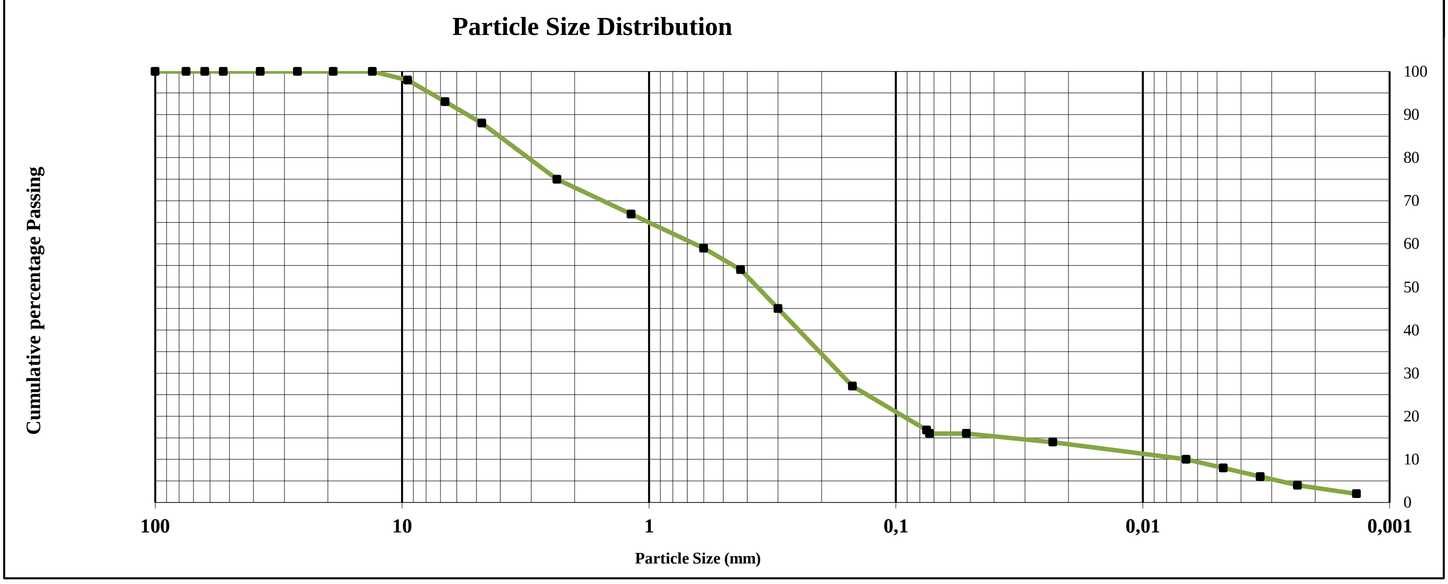
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Light Brown Olive Silty Soil with Calcrete	Sample Number:	13932		
Position:	TP59	Liquid Limit	**SP**	Linear Shrinkage	**1.2**
Depth:	0.2 - 1.5m	Plasticity Index	**SP**	Insitu M/C%	**8,8**

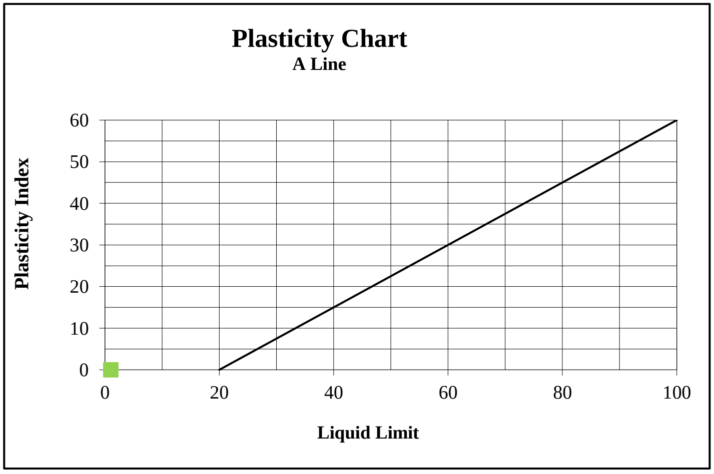
PH (TMH1 A20)*	**8,3**	**(TMH1 A21T)* Conductivity s.m^{-1}**	**0,719**	**COLTO SPEC**	

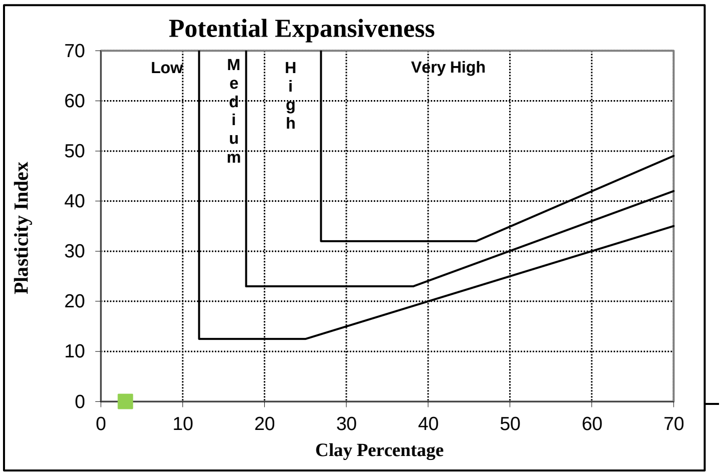
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,073	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	98	93	88	75	66,9	59	54	45	27	16,8	16	16	14	10	8	6	4	2
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel	27	**% Sand**	57	**% Silt**	13	**% Clay**	3





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Client:	**Zutari**
Project:	Ebenhauser
Attention:	Ms K Myburgh
Your Ref. No:	113834
Date Reported	31.08.20

TEST REPORT REFERENCE NUMBER / JOB NUMBER : SWL12343

Dear Sir / Madam

Herewith please find the original reports pertaining to the above mentioned project.

Test Requested

4	*x FOUNDATION INDICATORS*
1	*x MOD / CBR*
1	*x PH & CONDUCTIVITY*

Site Sampling and Materials Information

Sampling Method	Specimens delivered to Steyn Wilson Laboratory.
Environmental Condition	Sunny
Deviation from the prescribed test method	
Responsibility of information disclaimer	

● **FINAL REPORT**

We would like to take this opportunity to thank you for your valued support.
Should you have any further enquiries please don't hesitate to contact me.

Yours Faithfully
STEYN-WILSON LABORATORIES (PTY) LTD

Mr. R.Wilson
Technical Signatory

Remarks:

1. Information contained herein is confidential to STEYN-WILSON PTY LTD and the addressee
2. Opinions & Interpretations are not included in our schedule of Accreditation.
3. The samples where subjected and analysed according to ASTM.
4. The results reported relate only to the sample tested, Further use of the attached information is not the responsibility or liability of STEYN-WILSON LABORATORIES (PTY) LTD.
5. This document is the correct record of all measurements made, and may not be reproduced other than with full written approval from a director of STEYN-WILSON LABORATORIES (PTY) LTD.
6. Measuring equipment is traceable to national standards (Where applicable).
7. Should there be any deviation from the prescribed test method comments will be made thereof, pertaining to the test on the relevant materials report.
8. Uncertainty of measurement is calculated and corresponds to a coverage probability of approximately 95%. Available on request.
9. The decision rule states that the measurement of uncertainty can be applied by the customer to the test results, on request. It is not the responsibility or liability of STEYN-WILSON LABORATORIES (PTY) LTD.

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FINANCIAL MANAGER:	**Mr. D. Erasmus CA (SA)**
LABORATORY MANAGER:	**Mr. K. Booysen**
OPARATION MANAGER:	**Mr. J Brits**
GEOTECHNICAL MANAGER:	**Mr. F Coetzee**
QUALITY MANAGER:	**Mrs. M Steyn E-Com I Tech**

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	1 Century City Drive	Date Received :	01.08.20
	Century City	Date Reported :	31.08.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

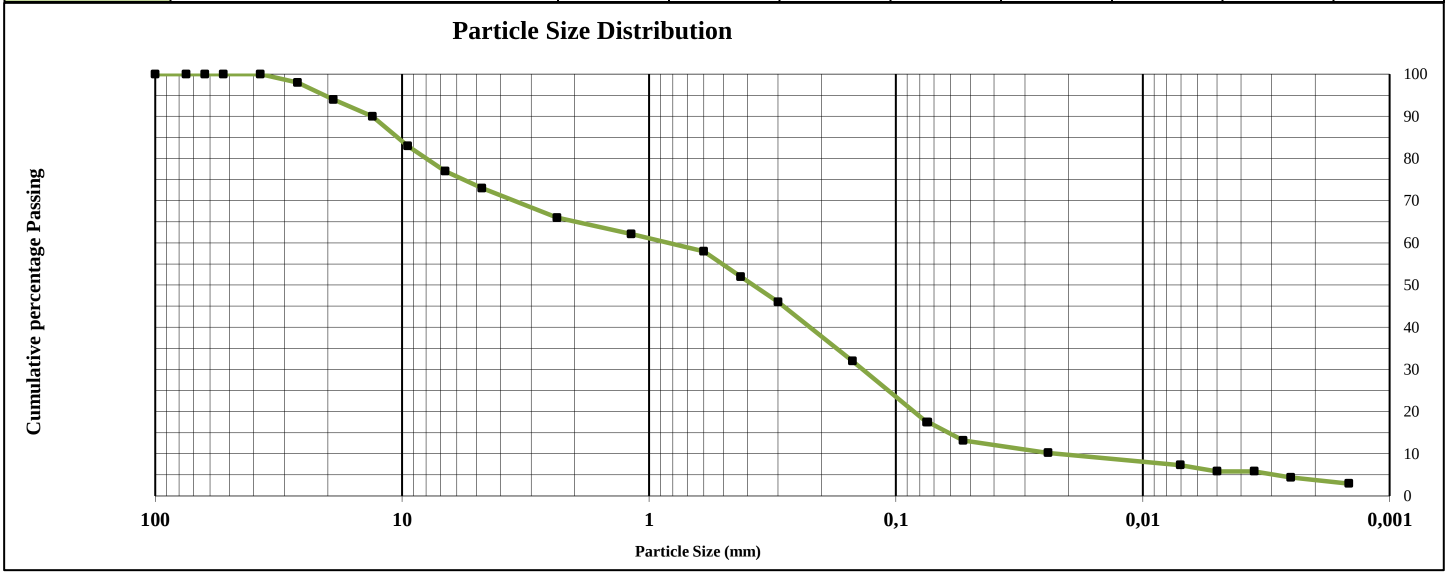
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Light Reddish Olive Silty Soil with Calcrete	Sample Number:	13933		
Position:	TP61	Liquid Limit	**NP**	Linear Shrinkage	**0,0**
Depth:	0.5 - 2.1m	Plasticity Index	**NP**	Insitu M/C%	**7,4**

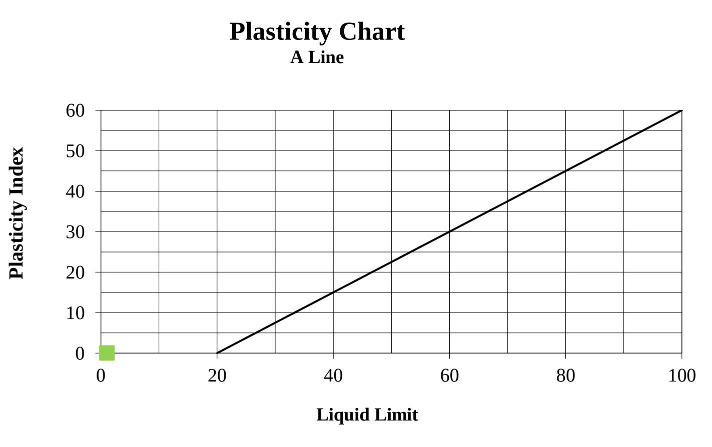
pH (TMH1 A20)*		**Conductivity s.m-1 (TMH1 A21T)***		**COLTO SPEC**	**G8**

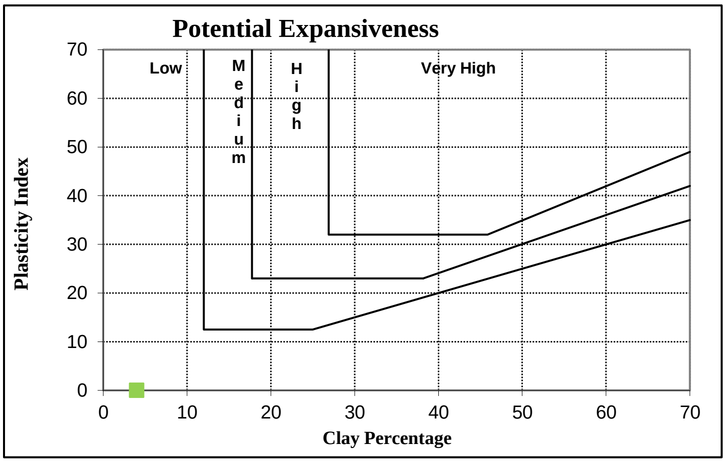
SIEVE ANALYSIS (TMH 1 A1a)*																		HYDROMETER ASTM D422							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,053	0,024	0,007	0,005	0,004	0,003	0,001
100	100	100	100	100	98	94	90	83	77	73	66	62,1	58	52	46	32	17,5	17,52	13,14	10,22	7,3	5,84	5,84	4,38	2,92
% Passing																									

MOD AASHTO SANS 3001 GR30		CBR SANS 3001 GR40							
OMC%	10,2	**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)	1980	10,6	0,0	32	25	22	17	12	8



% Gravel	**35**	**% Sand**	**50**	**% Silt**	**11**	**% Clay**	**4**





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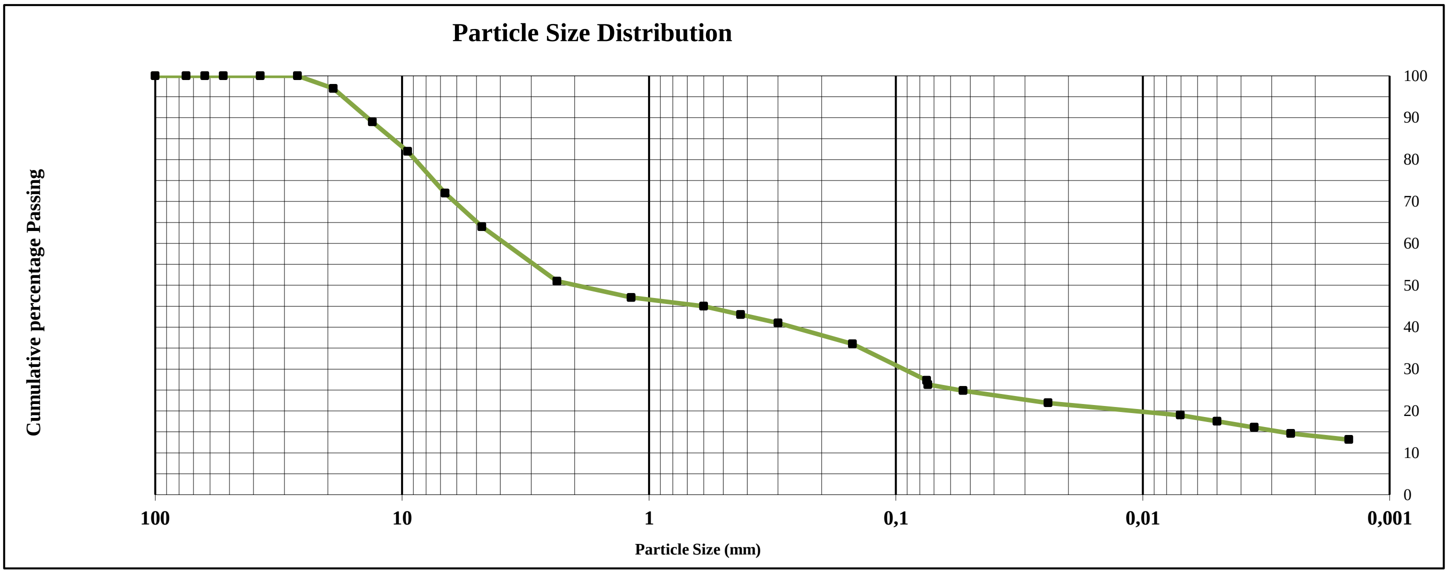
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Orange Brown Soil with Calcrete	Sample Number:	13934		
Position:	TP63	Liquid Limit	**23**	Linear Shrinkage	**3,8**
Depth:	0.0 - 0.6m	Plasticity Index	**7,9**	Insitu M/C%	**2,8**

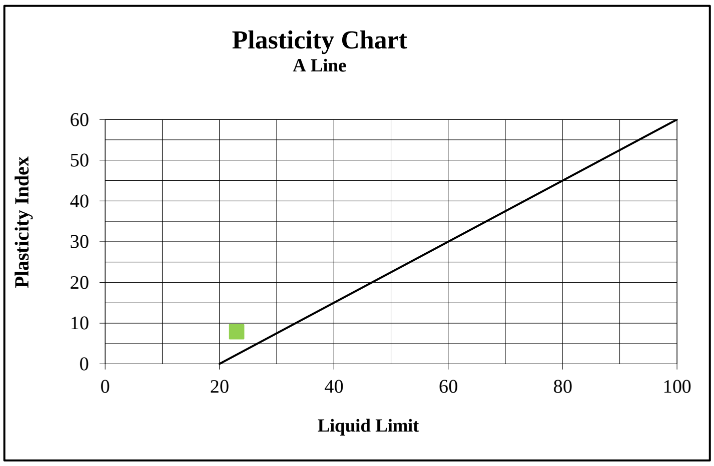
PH (TMH1 A20)*	**5,6**	**(TMH1 A21T)* Conductivity s.m^{-1}**	**0,113**	**COLTO SPEC**	

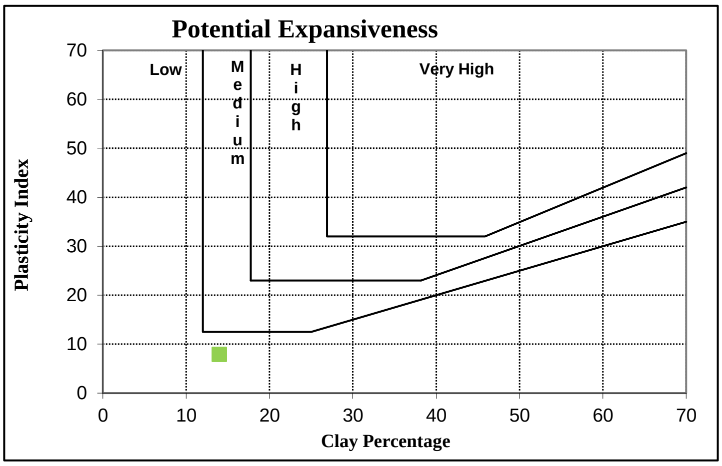
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,053	0,024	0,007	0,005	0,004	0,003	0,001
100	100	100	100	100	100	97	89	82	72	64	51	47,1	45	43	41	36	27,3	26,28	24,82	21,9	18,98	17,52	16,06	14,6	13,14
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel	**50**	**% Sand**	**25**	**% Silt**	**11**	**% Clay**	**14**





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Attention :	Ms K Myburgh		

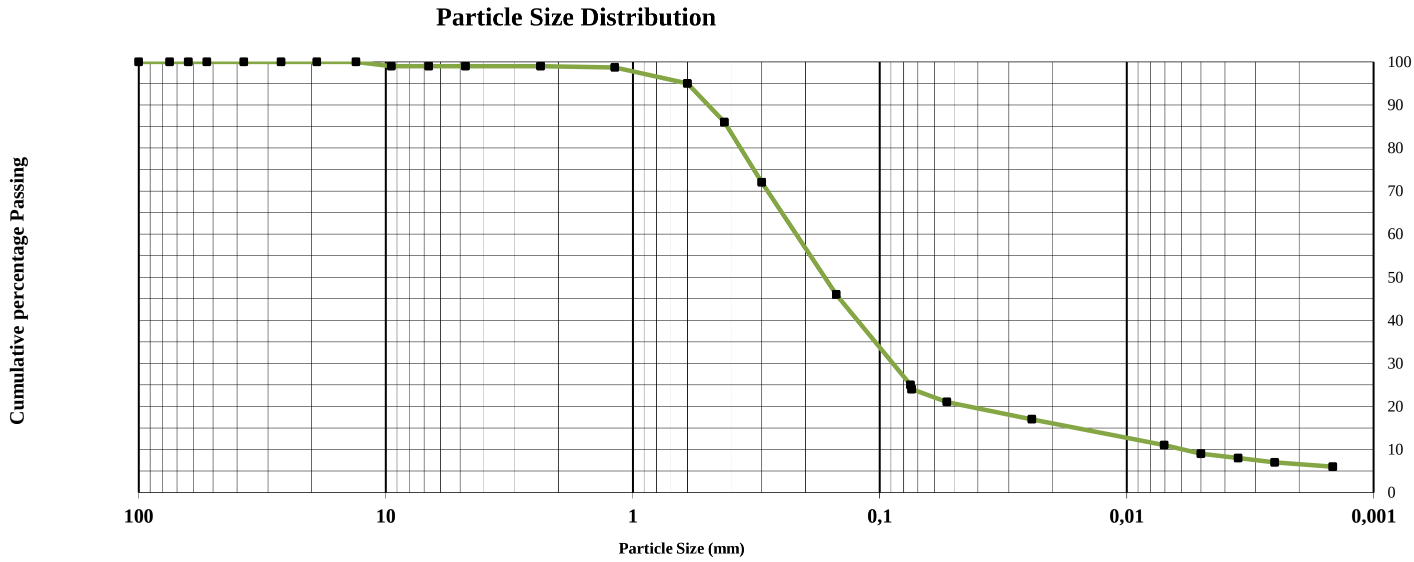
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Dark Reddish Brown Fine Sand	Sample Number:	13935		
Position:	TP66	Liquid Limit	**46**	Linear Shrinkage	**5,8**
Depth:	0.0 - 0.5m	Plasticity Index	**11,3**	Insitu M/C%	**5**

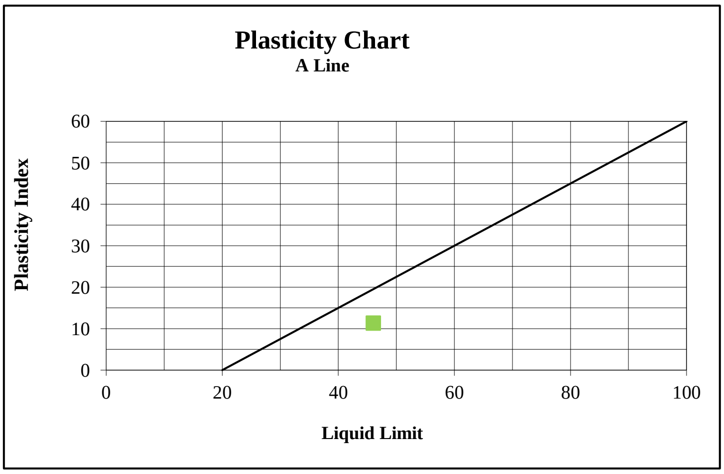
PH (TMH1 A20)*		**(TMH1 A21T)* Conductivity s.m^{-1}**		**COLTO SPEC**	

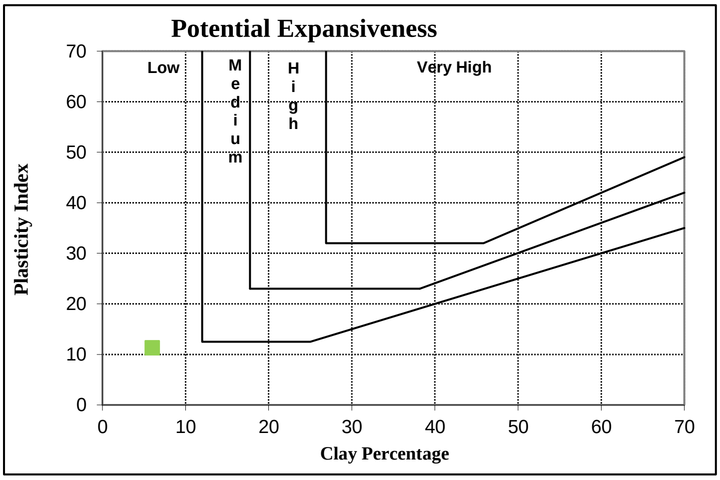
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,053	0,024	0,007	0,005	0,004	0,003	0,001
100	100	100	100	100	100	100	100	99	99	99	99	98,7	95	86	72	46	25	24	21	17	11	9	8	7	6
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel	1	**% Sand**	77	**% Silt**	16	**% Clay**	6





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MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

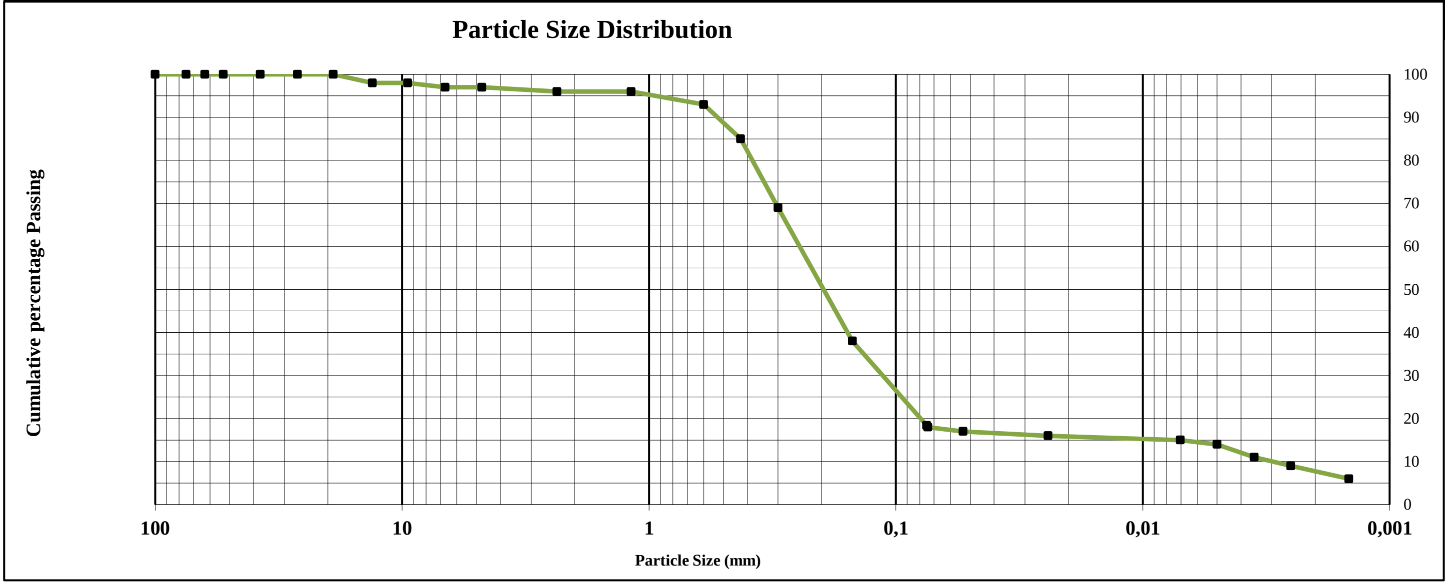
Material Description:	Dark Reddish Brown Fine Sand	Sample Number:	13956		
Position:	TP72	Liquid Limit	**38**	Linear Shrinkage	**5,3**
Depth:	Not specified	Plasticity Index	**11,7**	Insitu M/C%	**4,7**

PH (TMH1 A20)*		**(TMH1 A21T)* Conductivity s.m^{-1}**		**COLTO SPEC**	

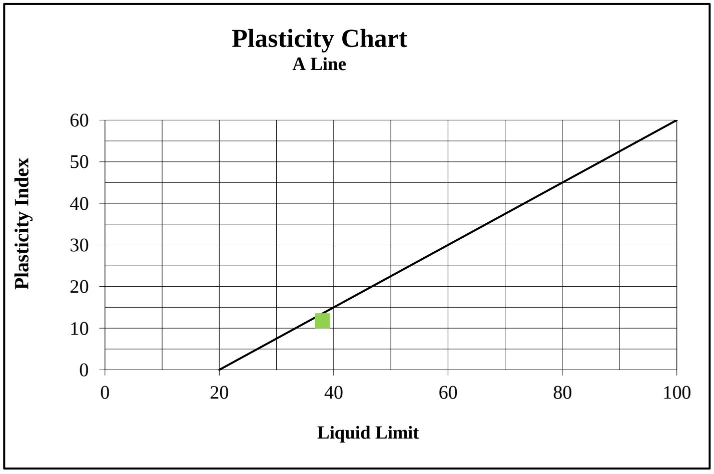
SIEVE ANALYSIS (TMH 1 A1a)*																		HYDROMETER ASTM D422							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,074	0,053	0,024	0,007	0,005	0,004	0,003	0,001
100	100	100	100	100	100	100	98	98	97	97	96	96	93	85	69	38	18,4	18	17	16	15	14	11	9	6

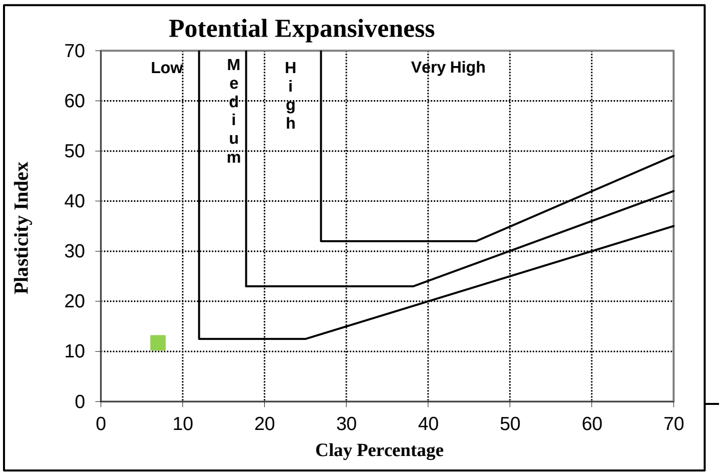
% Passing

MOD AASHTO SANS 3001 GR30		CBR SANS 3001 GR40							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel	4	% Sand	79	% Silt	10	% Clay	7





NOTE: All tests marked with (*) means that those test methods are not accredited.

STEYN-WILSON LABORATORIES
CIVIL ENGINEERING TESTING LABORATORIES

11 Gooderson Road Blackheath
PO Box 58 Blackheath 7581
Tel: 021 905 0435
Fax: 086 499 9482
Email: admin@steynwilson.co.za
Web: www.steynwilson.co.za

Client:	**Zutari**
Project:	Ebenhauser
Attention:	Ms K Myburgh
Your Ref. No:	113834
Date Reported	31.08.20

TEST REPORT REFERENCE NUMBER / JOB NUMBER : SWL12343

Dear Sir / Madam

Herewith please find the original reports pertaining to the above mentioned project.

Test Requested

2 x *FOUNDATION INDICATORS*

2 x *PH & CONDUCTIVITY*

Site Sampling and Materials Information

Sampling Method	Specimens delivered to Steyn Wilson Laboratory.
Environmental Condition	Sunny
Deviation from the prescribed test method	
Responsibility of information disclaimer	

● **FINAL REPORT**

We would like to take this opportunity to thank you for your valued support.
Should you have any further enquiries please don't hesitate to contact me.

Yours Faithfully
STEYN-WILSON LABORATORIES (PTY) LTD

Mr. R.Wilson
Technical Signatory

Remarks:
1. Information contained herein is confidential to STEYN-WILSON PTY LTD and the addressee
2. Opinions & Interpretations are not included in our schedule of Accreditation.
3. The samples where subjected and analysed according to ASTM.
4. The results reported relate only to the sample tested, Further use of the attached information is not the responsibility or liability of STEYN-WILSON LABORATORIES (PTY) LTD.
5. This document is the correct record of all measurements made, and may not be reproduced other than with full written approval from a director of STEYN-WILSON LABORATORIES (PTY) LTD.
6. Measuring equipment is traceable to national standards (Where applicable).
7. Should there be any deviation from the prescribed test method comments will be made thereof, pertaining to the test on the relevant materials report.
8. Uncertainty of measurement is calculated and corresponds to a coverage probability of approximately 95%. Available on request.
9. The decision rule states that the measurement of uncertainty can be applied by the customer to the test results, on request. It is not the responsibility or liability of STEYN-WILSON LABORATORIES (PTY) LTD.

Customer : **Zutari**
1 Century City Drive
Century City
7446
Attention : Ms K Myburgh

Project : Ebenhauser
Date Received : 01.08.20
Date Reported : 31.08.20
Req. Number : 113834

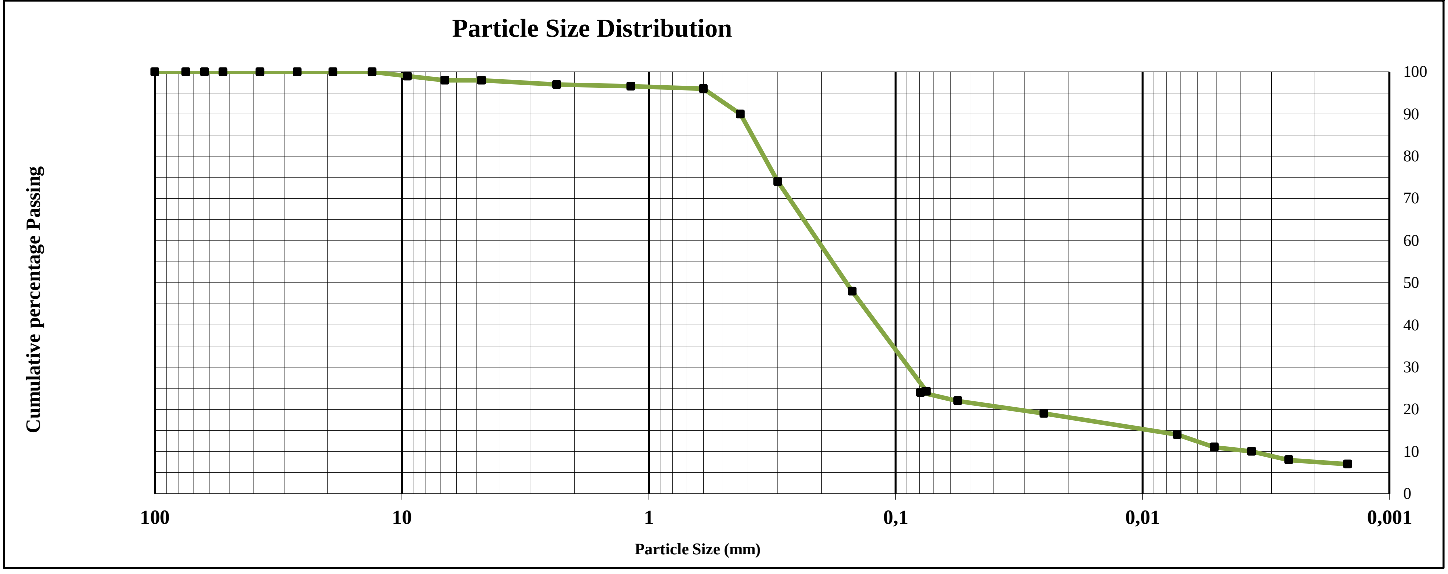
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Dark Reddish Brown Fine Sand	Sample Number:	13937		
Position:	TP73	Liquid Limit	**33**	Linear Shrinkage	**4,9**
Depth:	0.0 - 0.4m	Plasticity Index	**10,5**	Insitu M/C%	**4**

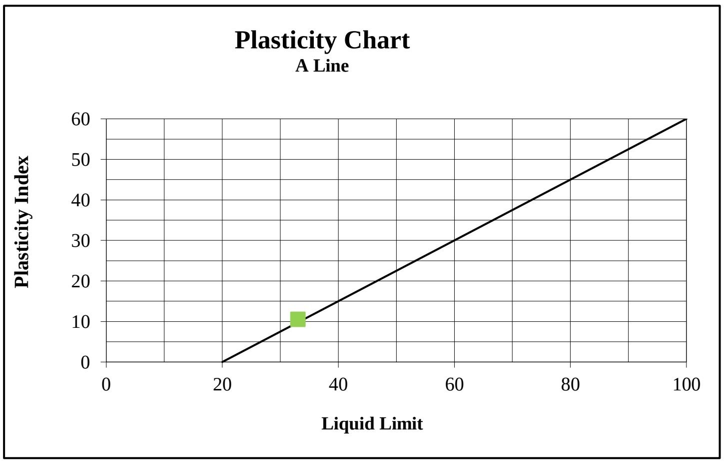
pH (TMH1 A20)*	**7,4**	**Conductivity s.m-1 (TMH1 A21T)***	**0,008**	**COLTO SPEC**	

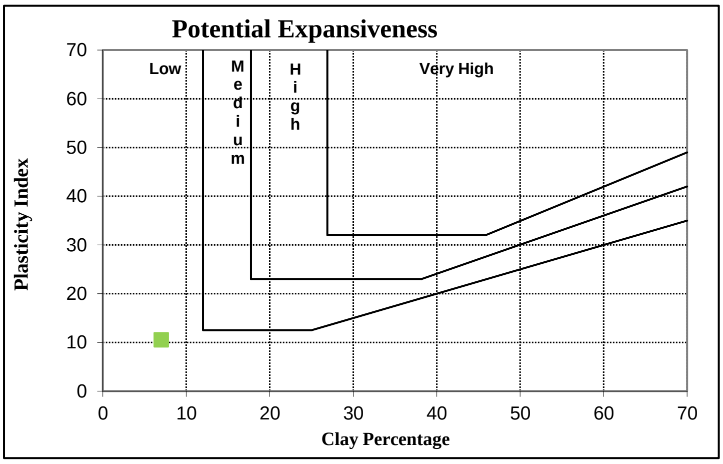
SIEVE ANALYSIS (TMH 1 A1a)*																		HYDROMETER ASTM D422							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,079	0,056	0,025	0,007	0,005	0,004	0,003	0,001
100	100	100	100	100	100	100	100	99	98	98	97	96,6	96	90	74	48	24,3	24	22	19	14	11	10	8	7
% Passing																									

MOD AASHTO SANS 3001 GR30		CBR SANS 3001 GR40							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									


Particle Size Distribution

% Gravel	**3**	**% Sand**	**75**	**% Silt**	**15**	**% Clay**	**7**


Plasticity Chart


Potential Expansiveness

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Customer : **Zutari**
1 Century City Drive
Century City
7446
Attention : Ms K Myburgh

Project : Ebenhauser
Date Received : 01.08.20
Date Reported : 31.08.20
Req. Number : 113834

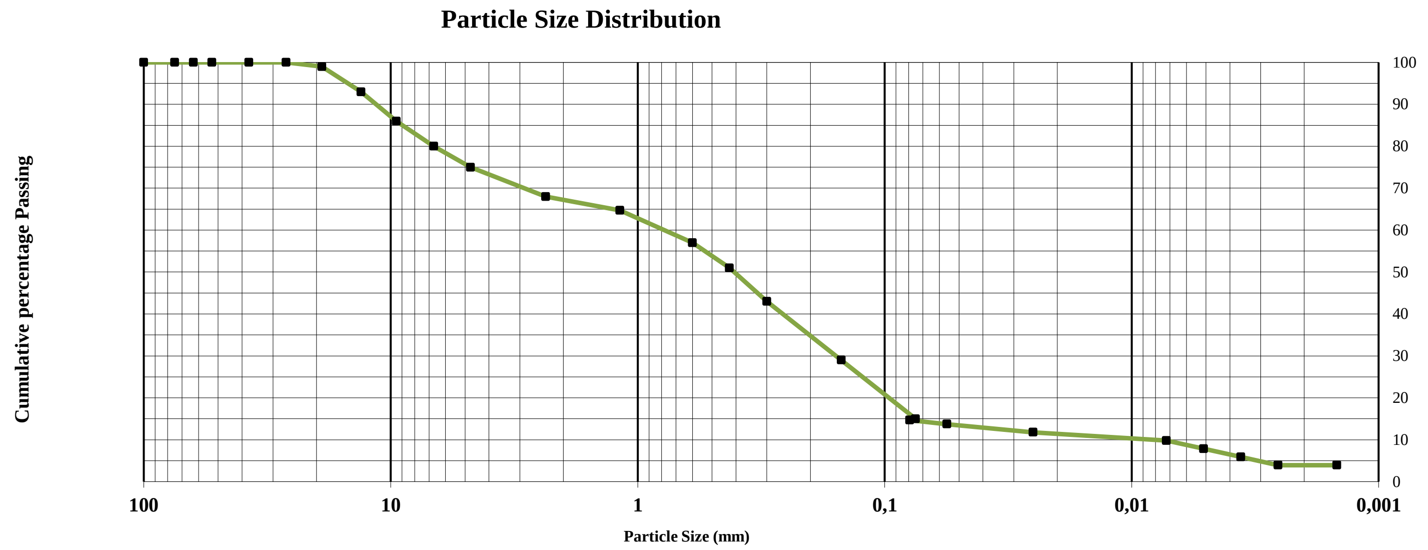
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Light Reddish Olive Silty Soil with Ferricrete	Sample Number:	13936		
Position:	TP78	Liquid Limit	**NP**	Linear Shrinkage	**0,0**
Depth:	0.3 - 0.6m	Plasticity Index	**NP**	Insitu M/C%	**11**

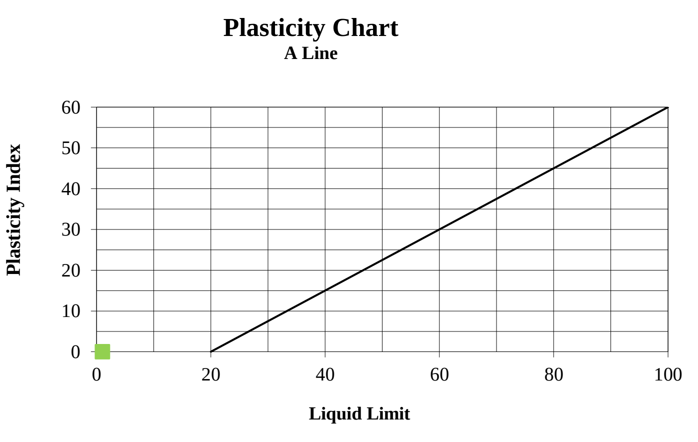
PH (TMH1 A20)*	**7,2**	**(TMH1 A21T)* Conductivity s.m^{-1}**	**0,146**	**COLTO SPEC**	

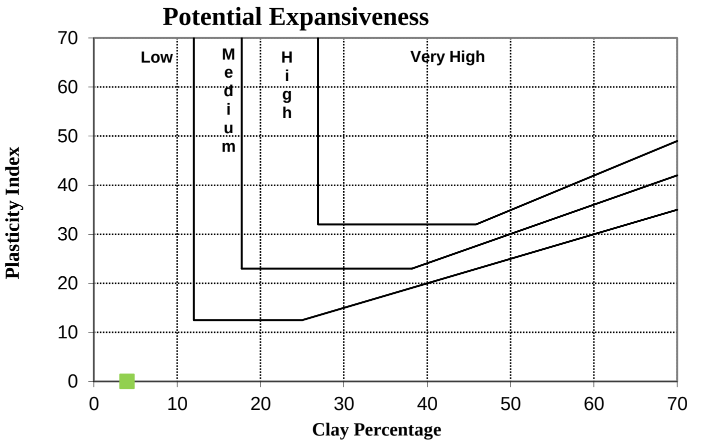
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,079	0,056	0,025	0,007	0,005	0,004	0,003	0,001
100	100	100	100	100	100	99	93	86	80	75	68	64,7	57	51	43	29	15	14,7	13,72	11,76	9,8	7,84	5,88	3,92	3,92
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel	**33**	**% Sand**	**53**	**% Silt**	**10**	**% Clay**	**4**





NOTE: All tests marked with (*) means that those test methods are not accredited.

Direct Shear Test

Initial Sample Details

		Specimen 1	Specimen 2	Specimen 3
Height	(mm)	20.0	20.0	20.0
Diameter	(mm)	60.0	60.0	60.0
Mass	(g)	124.0	124.0	124.1
Moisture	(%)	10.4	10.4	10.4
Dry Density	(Mg/m^3)	1.99	1.99	1.99
Bulk Density	(Mg/m^3)	2.19	2.19	2.19
Void Ratio		0.309	0.309	0.308
Particle Density	(Mg/m^3)	2.60		
Sample Method		Bag		
Disturbed/Undisturbed		Disturbed		
Remoulded Desity	(Mg/m^3)	1.99 (98%)		

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3
Vertical Displacement	(mm)	0.460	0.750	0.948
Void Ratio After Consolidation		0.279	0.260	0.246

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3
Normal Stress	(kPa)	50	100	150
Peak Shear Stress	(kPa)	45.3	79.9	114.9
Horizontal Strain at Failure	(mm)	2.2	2.3	2.9
Verical Stain at Failure	(mm)	0.238	0.300	0.482
Rate of Shear	(mm/min)	0.019	0.012	0.022
Friction Angle (ϕ)	(°)	34.8		
Cohesion (c)	(kPa)	10.56		

Final Sample Details

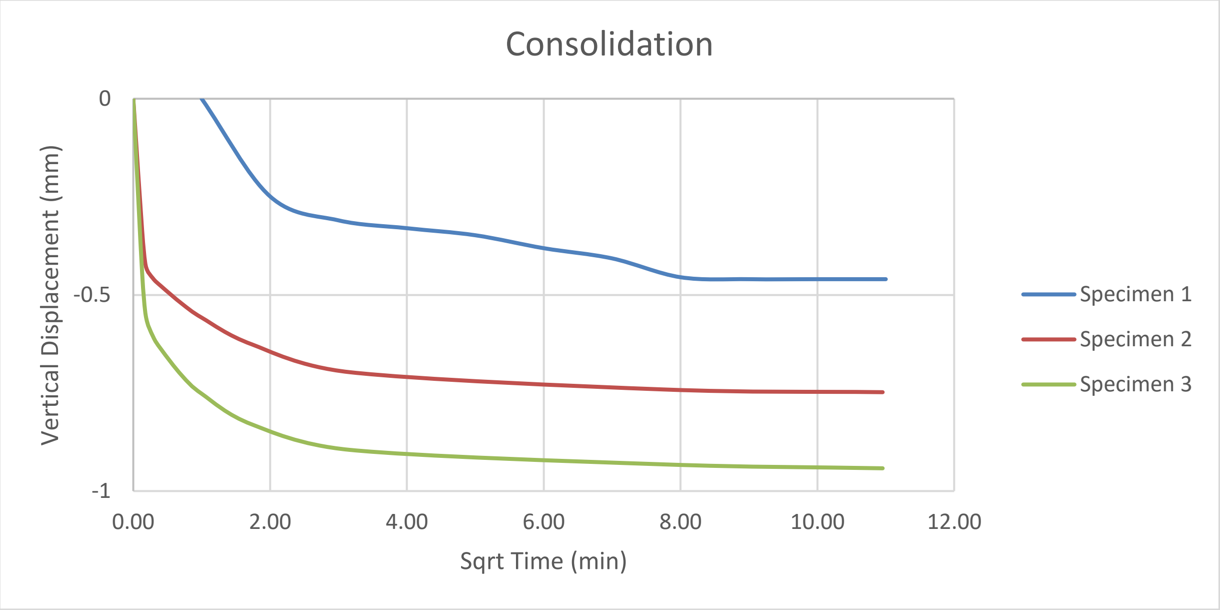
		Specimen 1	Specimen 2	Specimen 3
Mass	(g)	123.5	124.5	123.1
Moisture	(%)	12.9	13.2	12.8
Void Ratio		0.263	0.240	0.214

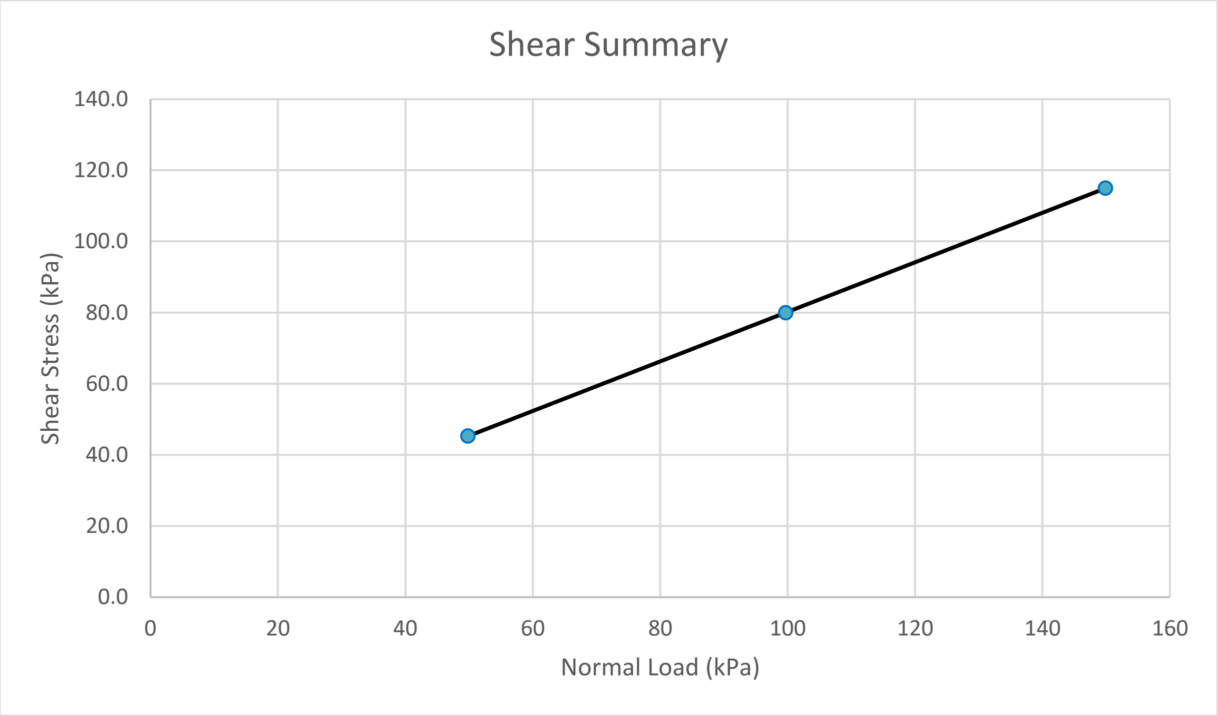
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	21/09/2020
	Jobfile	SWG00088	Sample	E TP07_0.3-3.0m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	34.8
Cohesion (c)	(kPa)	10.56



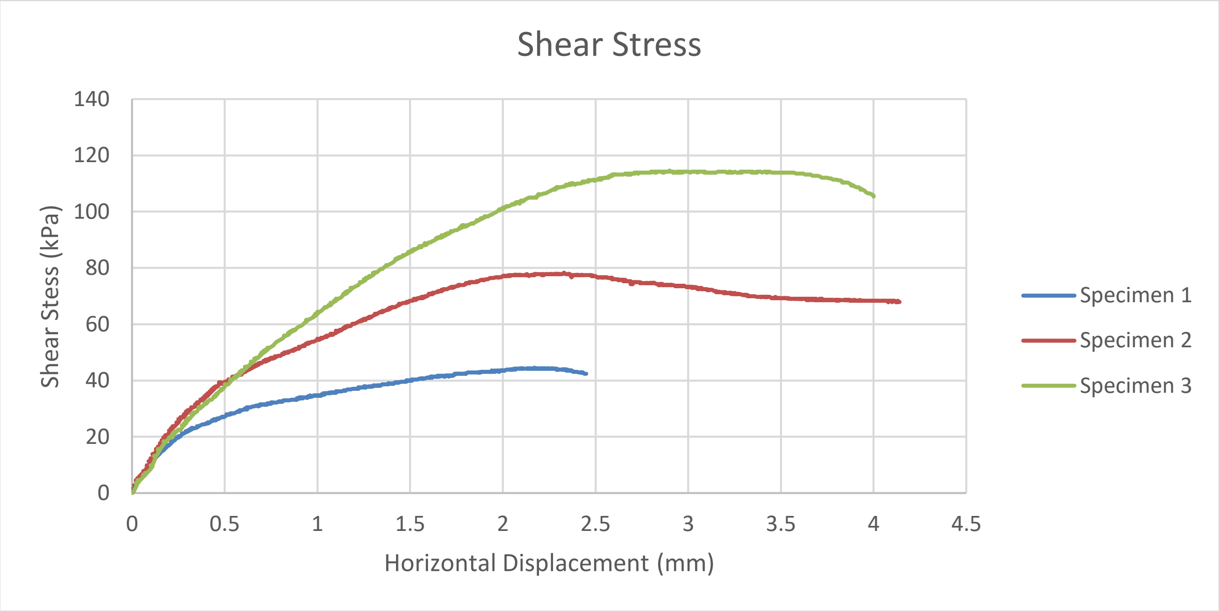


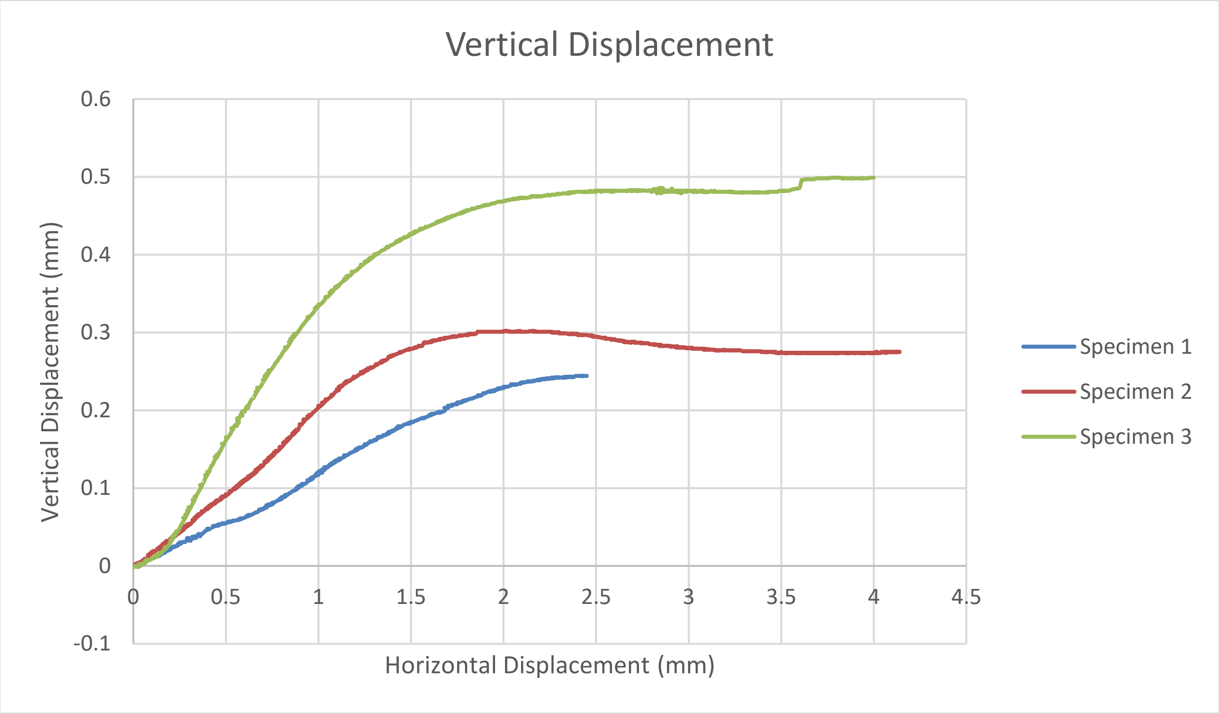
STEYN-WILSON GEOTECHNICAL	Test Method BS1377 - 7: 1990		Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech
	Site Reference Jobfile SWG00088 Client Zutari		Test Date 21/09/2020 Sample E TP07_0.3-3.0m Borehole Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	34.8
Cohesion (c)	(kPa)	10.56





STEYN-WILSON GEOTECHNICAL	Test Method BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference	Test Date	21/09/2020
	Jobfile SWG00088	Sample	E TP07_0.3-3.0m
	Client Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC

Direct Shear Test

Initial Sample Details

		Specimen 1	Specimen 2	Specimen 3
Height	(mm)	20.0	20.0	20.0
Diameter	(mm)	60.0	60.0	60.0
Mass	(g)	114.9	114.9	114.8
Moisture	(%)	11.6	11.6	11.6
Dry Density	(Mg/m^3)	1.82	1.82	1.82
Bulk Density	(Mg/m^3)	2.03	2.03	2.03
Void Ratio		0.423	0.423	0.424
Particle Density	(Mg/m^3)	2.59		
Sample Method		Bag		
Disturbed/Undisturbed		Disturbed		
Remoulded Desity	(Mg/m^3)	1.85 (98%)		

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3
Vertical Displacement	(mm)	0.281	0.403	0.456
Void Ratio After Consolidation		0.403	0.394	0.391

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3
Normal Stress	(kPa)	50	100	142
Peak Shear Stress	(kPa)	41.7	79.2	114.2
Horizontal Strain at Failure	(mm)	3.0	2.3	2.3
Verical Stain at Failure	(mm)	0.168	0.210	0.206
Rate of Shear	(mm/min)	0.047	0.018	0.058
Friction Angle (ϕ)	(°)	38.3		
Cohesion (c)	(kPa)	1.78		

Final Sample Details

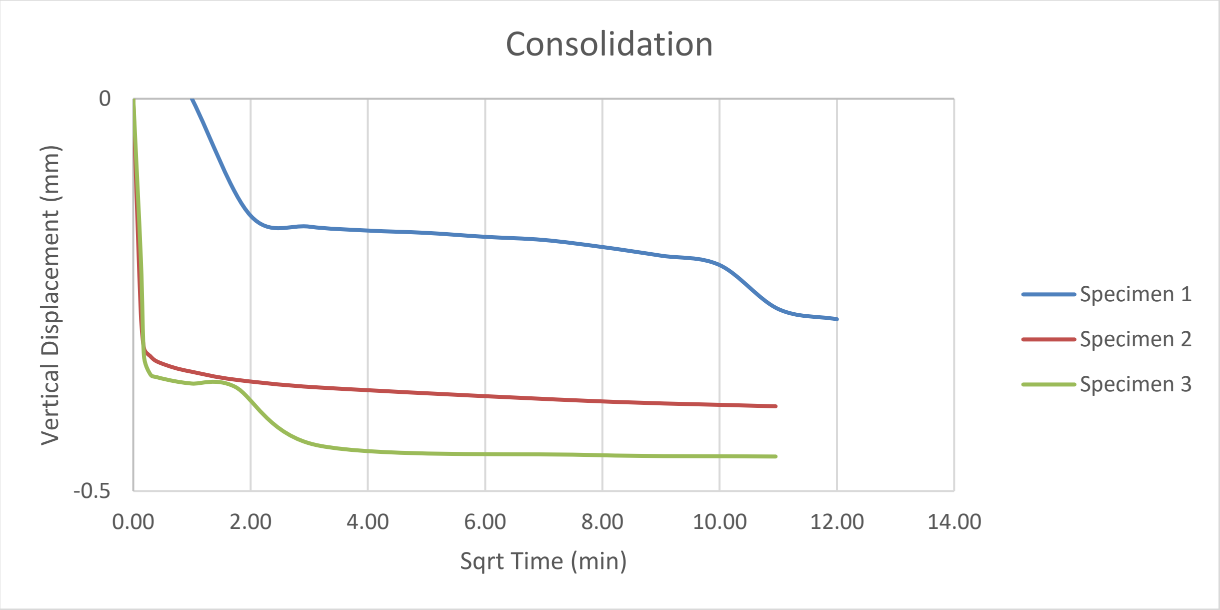
		Specimen 1	Specimen 2	Specimen 3
Mass	(g)	111.4	115.7	114.8
Moisture	(%)	17.1	17.3	18.4
Void Ratio		0.391	0.379	0.377

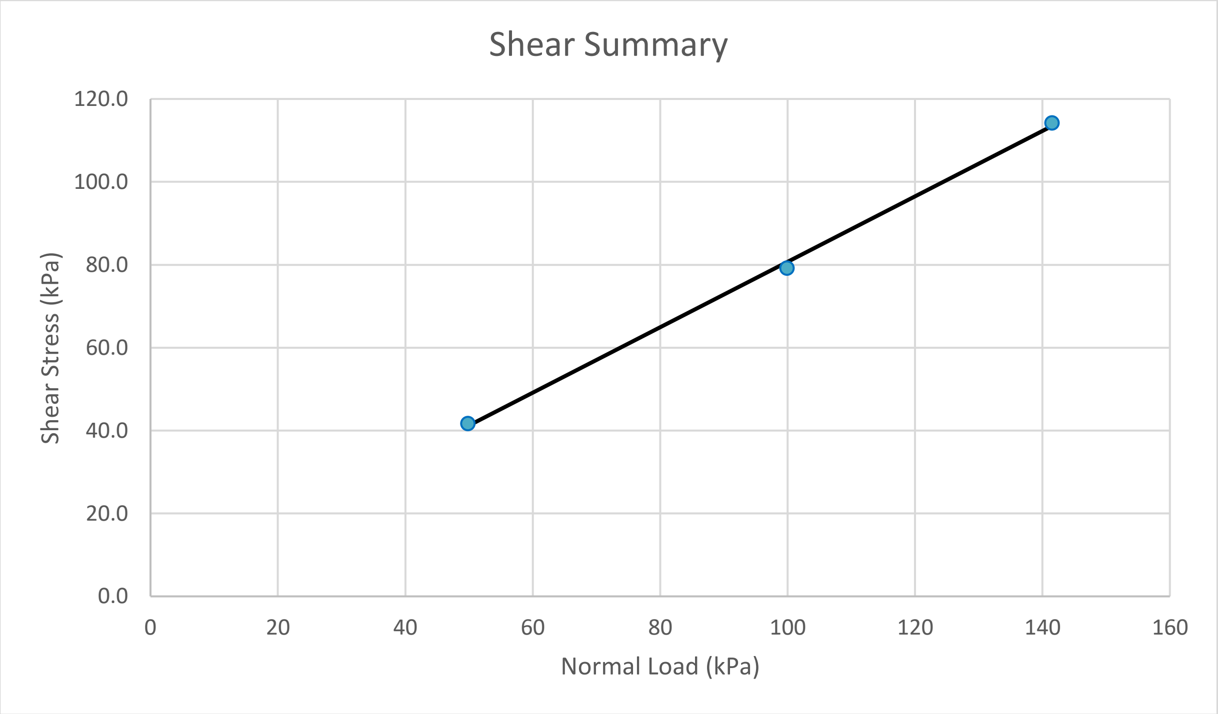
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	05/03/2020
	Jobfile	SWG00088	Sample	E_TP09_0.0-3.0m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	38.3
Cohesion (c)	(kPa)	1.78





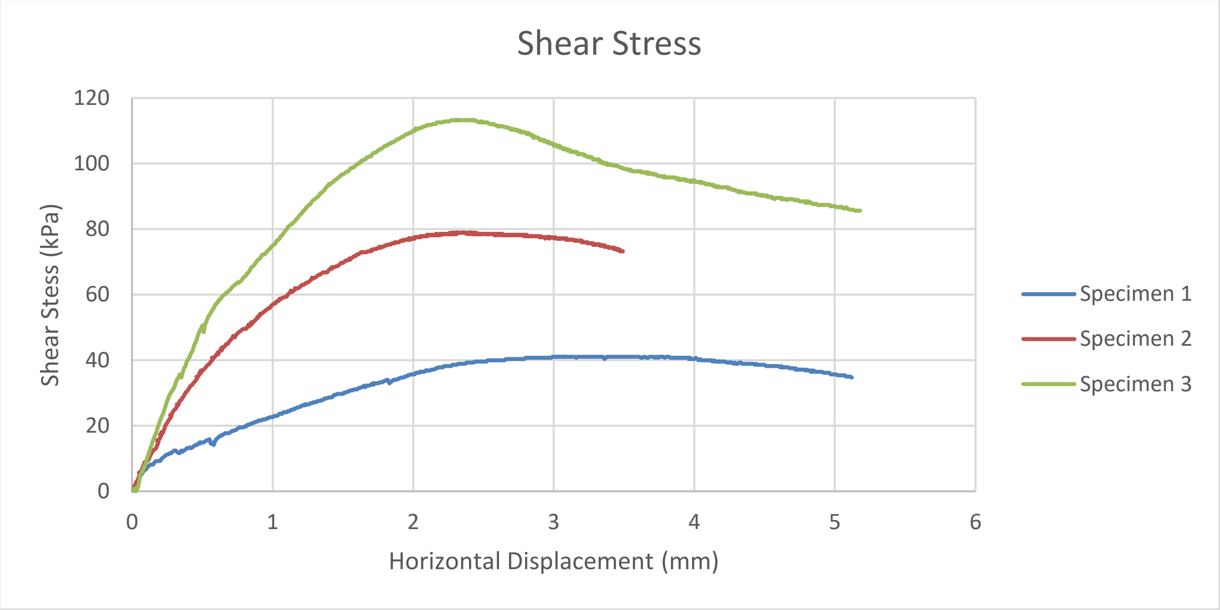
Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
Site Reference		Test Date	05/03/2020
Jobfile	SWG00088	Sample	E_TP09_0.0-3.0m
Client	Zutari	Borehole	Clanwilliam Bridging Study
Operator:FC	Checked: FC	Approved: FC	

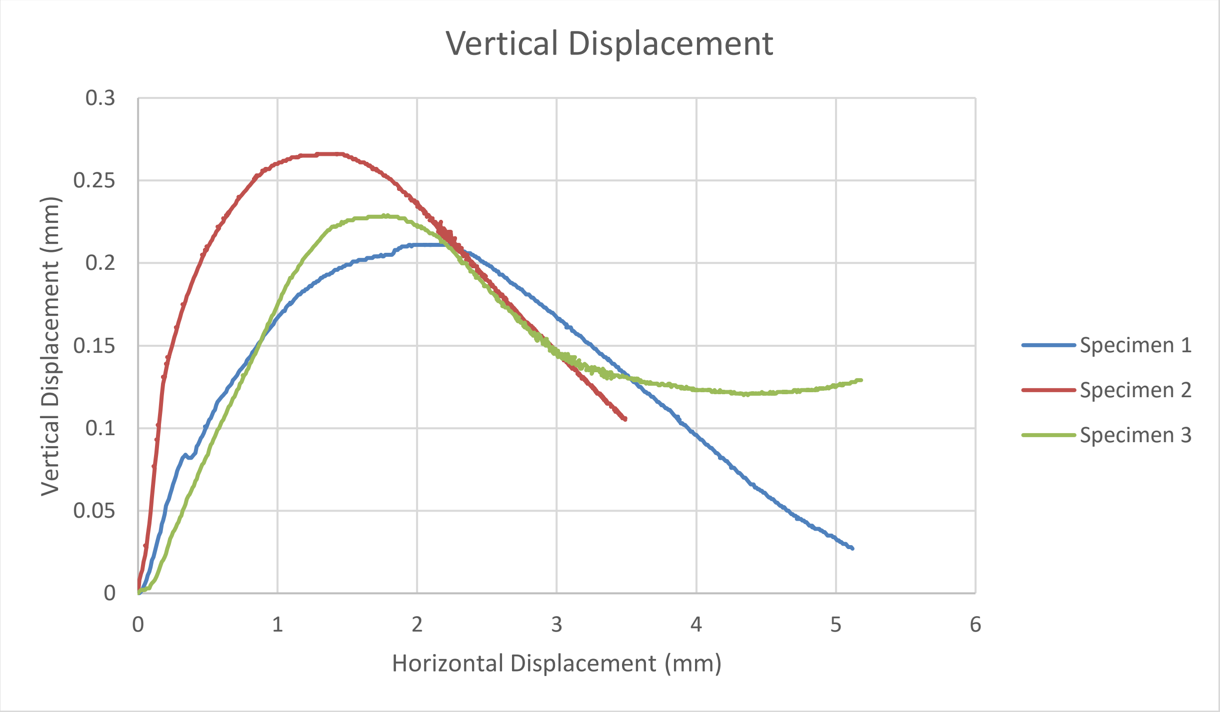
STEYN-WILSON GEOTECHNICAL

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	38.3
Cohesion (c)	(kPa)	1.78





STEYN-WILSON GEOTECHNICAL	Test Method BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference	Test Date	05/03/2020
	Jobfile SWG00088	Sample	E_TP09_0.0-3.0m
	Client Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC

Direct Shear Test

Initial Sample Details

		Specimen 1	Specimen 2	Specimen 3
Height	(mm)	20.0	20.0	20.0
Diameter	(mm)	60.0	60.0	60.0
Mass	(g)	120.0	120.1	120.1
Moisture	(%)	10.0	10.0	10.0
Dry Density	(Mg/m^3)	1.93	1.93	1.93
Bulk Density	(Mg/m^3)	2.12	2.12	2.12
Void Ratio		0.348	0.347	0.347
Particle Density	(Mg/m^3)	2.60		
Sample Method		Bag		
Disturbed/Undisturbed		Disturbed		
Remoulded Desity	(Mg/m^3)	1.93 (98%)		

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3
Vertical Displacement	(mm)	0.397	0.515	0.663
Void Ratio After Consolidation		0.321	0.312	0.302

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3
Normal Stress	(kPa)	50	100	150
Peak Shear Stress	(kPa)	55.5	89.1	132.6
Horizontal Strain at Failure	(mm)	1.1	1.8	1.9
Verical Stain at Failure	(mm)	0.026	0.172	0.221
Rate of Shear	(mm/min)	0.017	0.020	0.021
Friction Angle (ϕ)	(°)	37.6		
Cohesion (c)	(kPa)	15.51		

Final Sample Details

		Specimen 1	Specimen 2	Specimen 3
Mass	(g)	125.1	125.1	124.9
Moisture	(%)	20.3	21.5	19.0
Void Ratio		0.319	0.300	0.287

STEYN-WILSON
GEOTECHNICAL

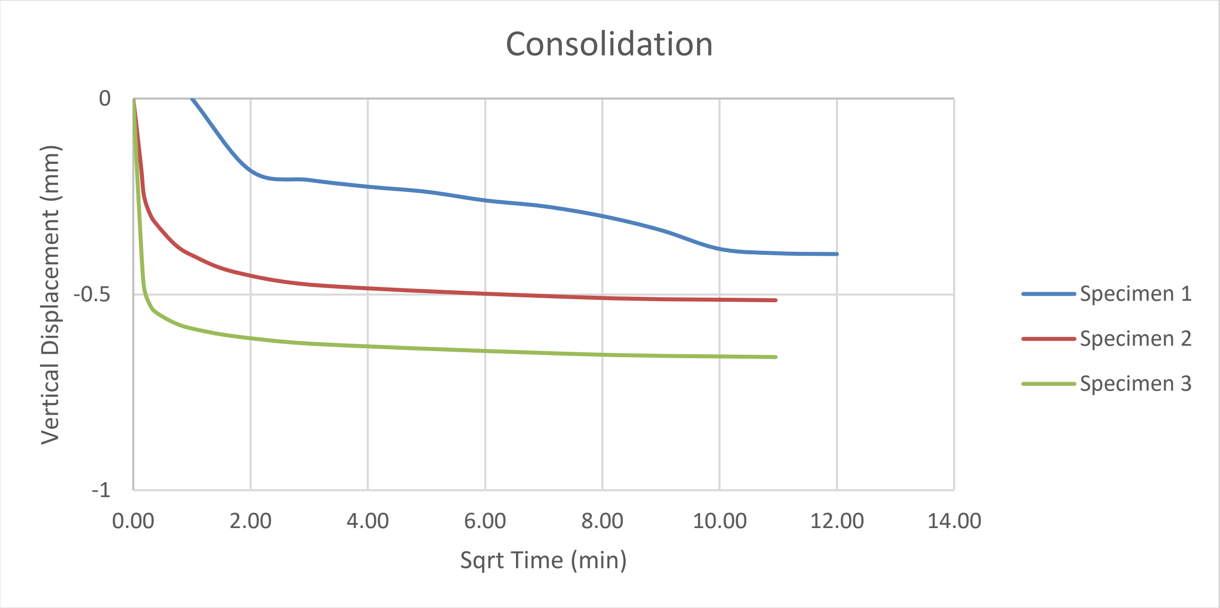
Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
Site Reference		Test Date	22/09/2020
Jobfile	SWG00088	Sample	E TP10_1.0-2.0m
Client	Zutari	Borehole	Clanwilliam Bridging Study

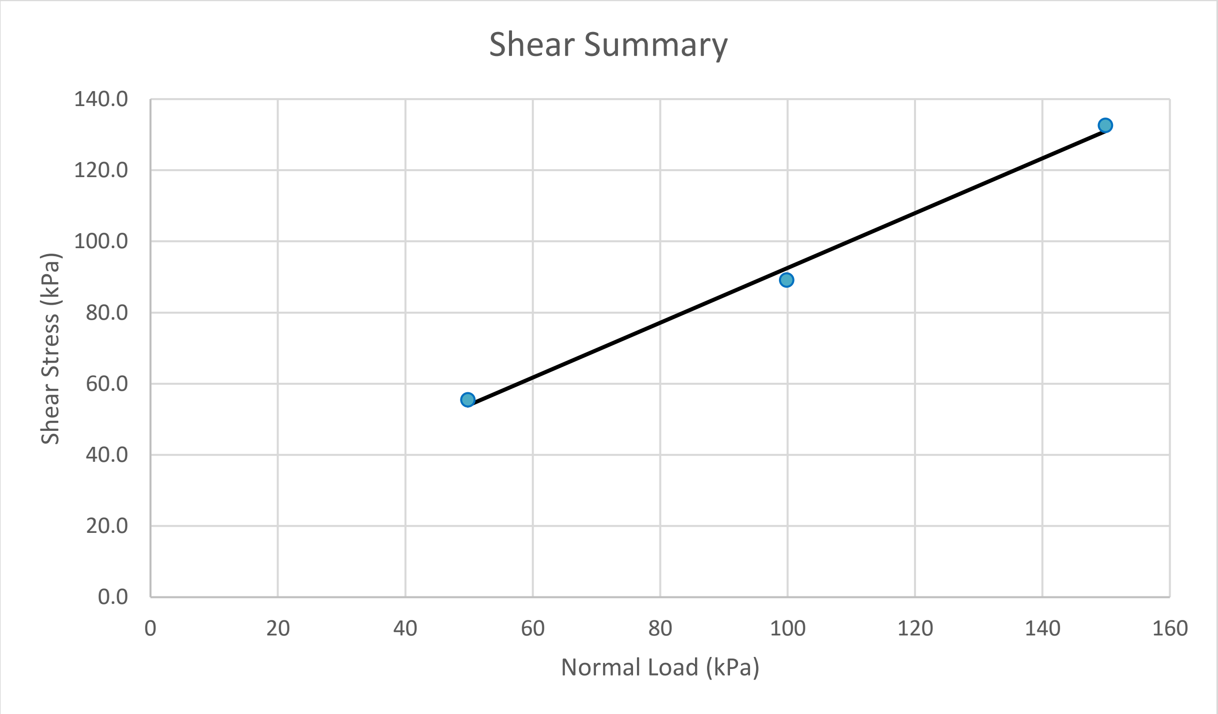
Operator:FC Checked: FC Approved: FC

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	37.6
Cohesion (c)	(kPa)	15.51



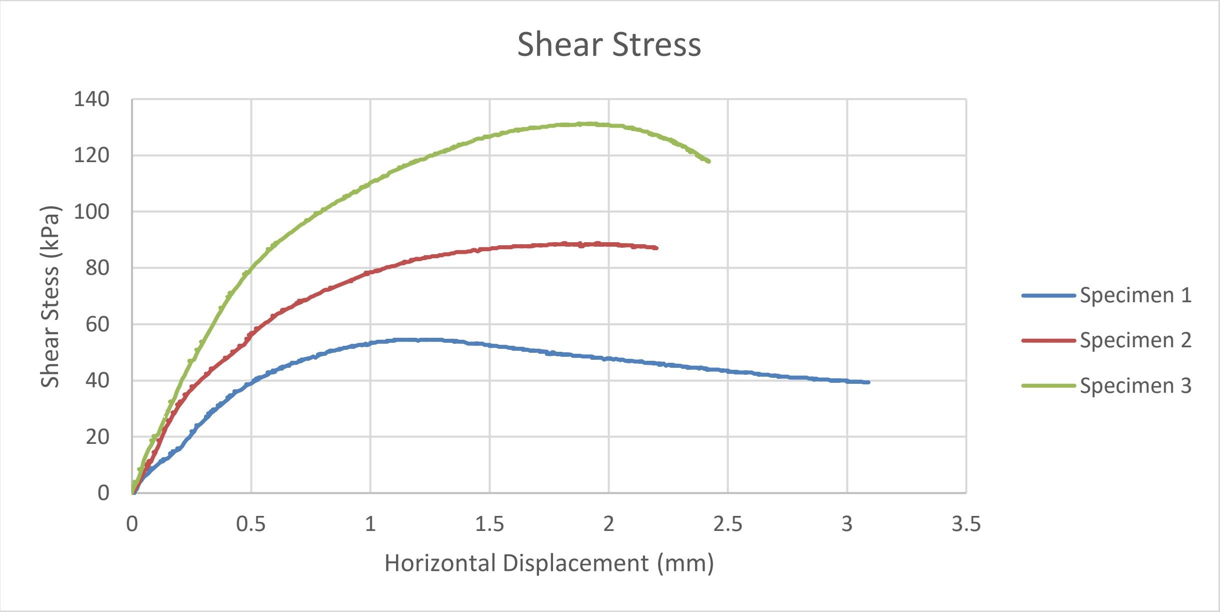


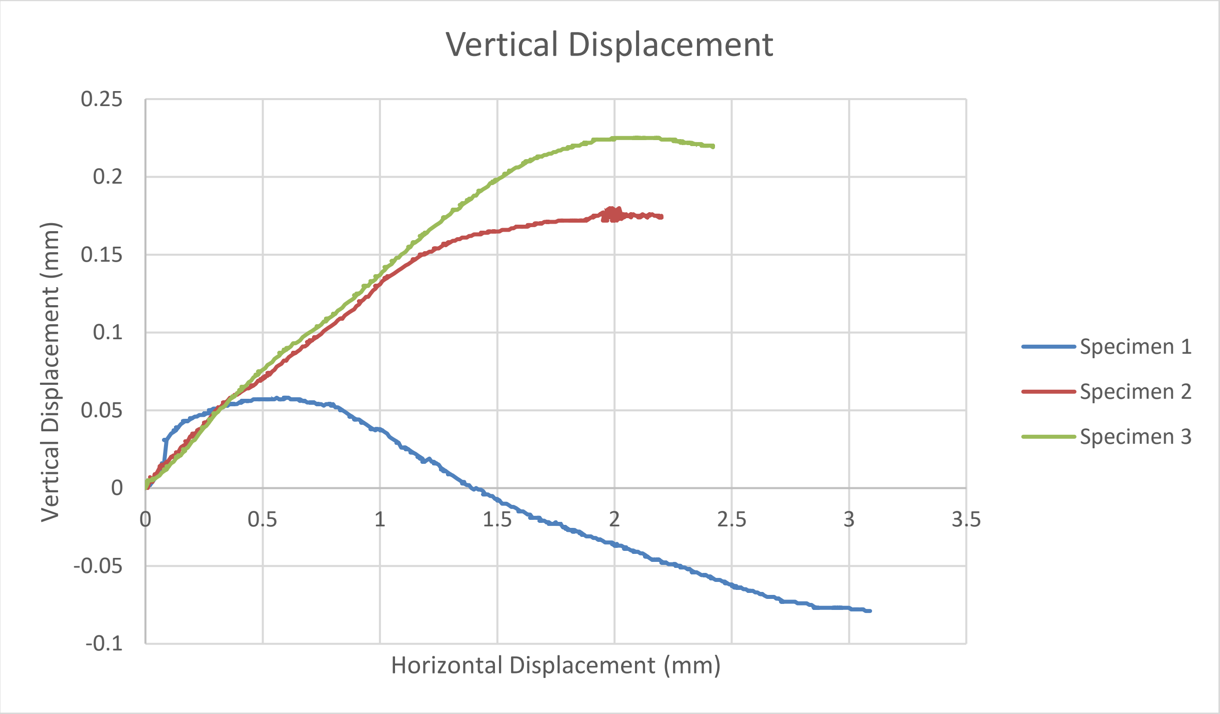
STEYN-WILSON GEOTECHNICAL	Test Method BS1377 - 7: 1990		Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech
	Site Reference		Test Date	22/09/2020
	Jobfile	SWG00088	Sample	E TP10_1.0-2.0m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	37.6
Cohesion (c)	(kPa)	15.51





STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech
	Site Reference Jobfile SWG00088 Client Zutari		Test Date 22/09/2020 Sample E TP10_1.0-2.0m Borehole Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC

Direct Shear Test

Initial Sample Details

		Specimen 1	Specimen 2	Specimen 3
Height	(mm)	20.0	20.0	20.0
Diameter	(mm)	60.0	60.0	60.0
Mass	(g)	107.3	107.1	107.3
Moisture	(%)	10.8	10.8	10.8
Dry Density	(Mg/m^3)	1.71	1.71	1.71
Bulk Density	(Mg/m^3)	1.90	1.89	1.90
Void Ratio		0.518	0.521	0.518
Particle Density	(Mg/m^3)	2.60		
Sample Method		Bag		
Disturbed/Undisturbed		Disturbed		
Remoulded Desity	(Mg/m^3)	98% (1.71)		

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3
Vertical Displacement	(mm)	0.107	0.200	0.665
Void Ratio After Consolidation		0.510	0.506	0.468

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3
Normal Stress	(kPa)	50	100	144
Peak Shear Stress	(kPa)	40.0	73.2	112.5
Horizontal Strain at Failure	(mm)	1.7	1.7	1.8
Verical Stain at Failure	(mm)	0.095	-0.015	0.113
Rate of Shear	(mm/min)	0.027	0.038	0.039
Friction Angle (ϕ)	(°)	37.4		
Cohesion (c)	(kPa)	0.28		

Final Sample Details

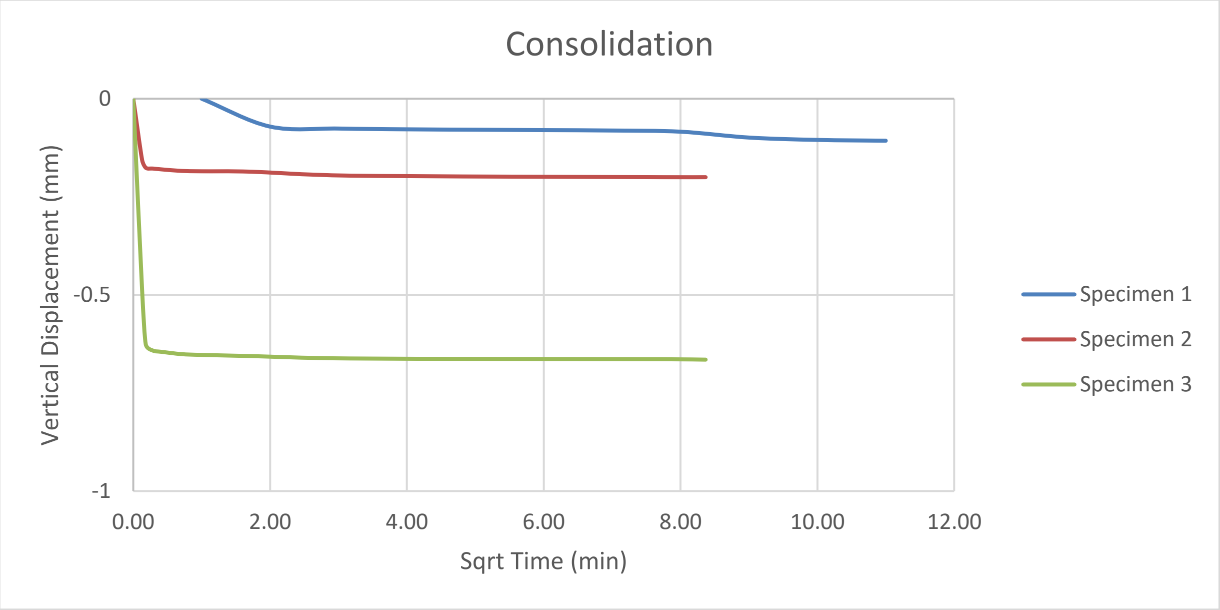
		Specimen 1	Specimen 2	Specimen 3
Mass	(g)	108.4	107.5	109.8
Moisture	(%)	19.1	19.2	19.1
Void Ratio		0.503	0.507	0.459

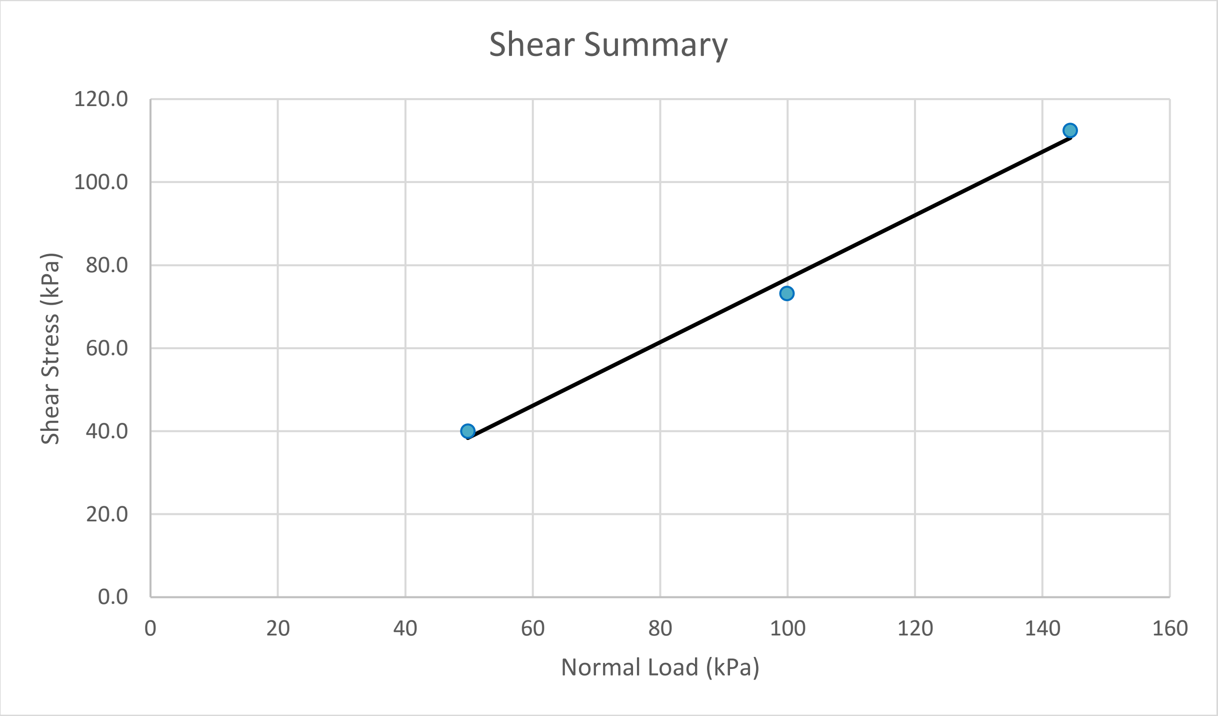
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	14/09/2020
	Jobfile	SWG00088	Sample	E_TP14_0.0-1.7m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	37.4
Cohesion (c)	(kPa)	0.28



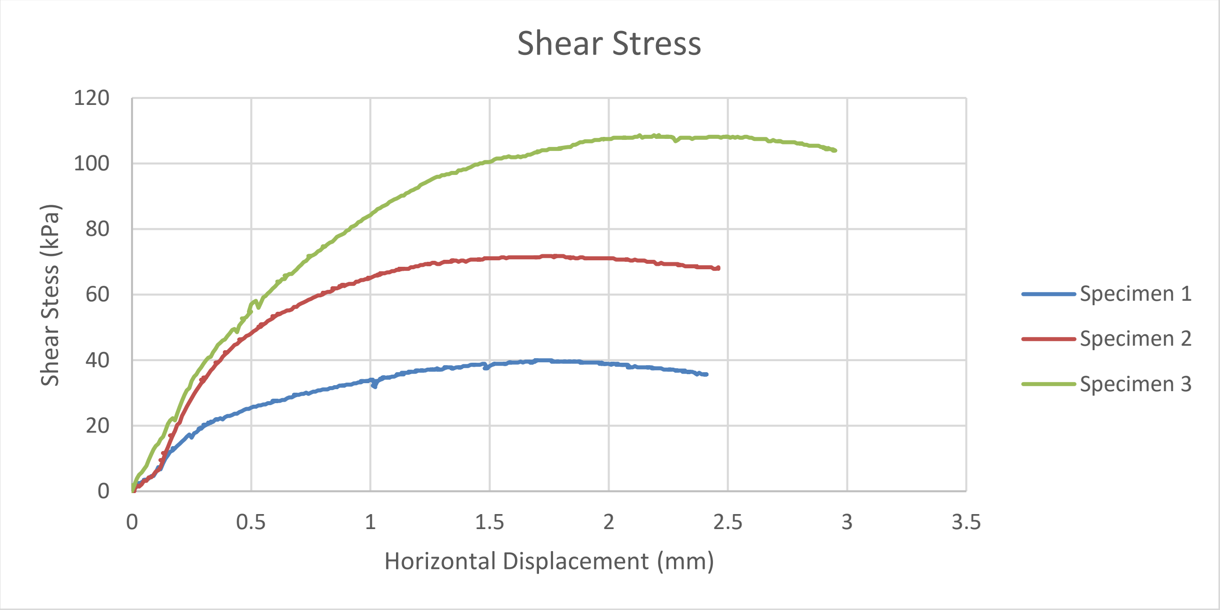


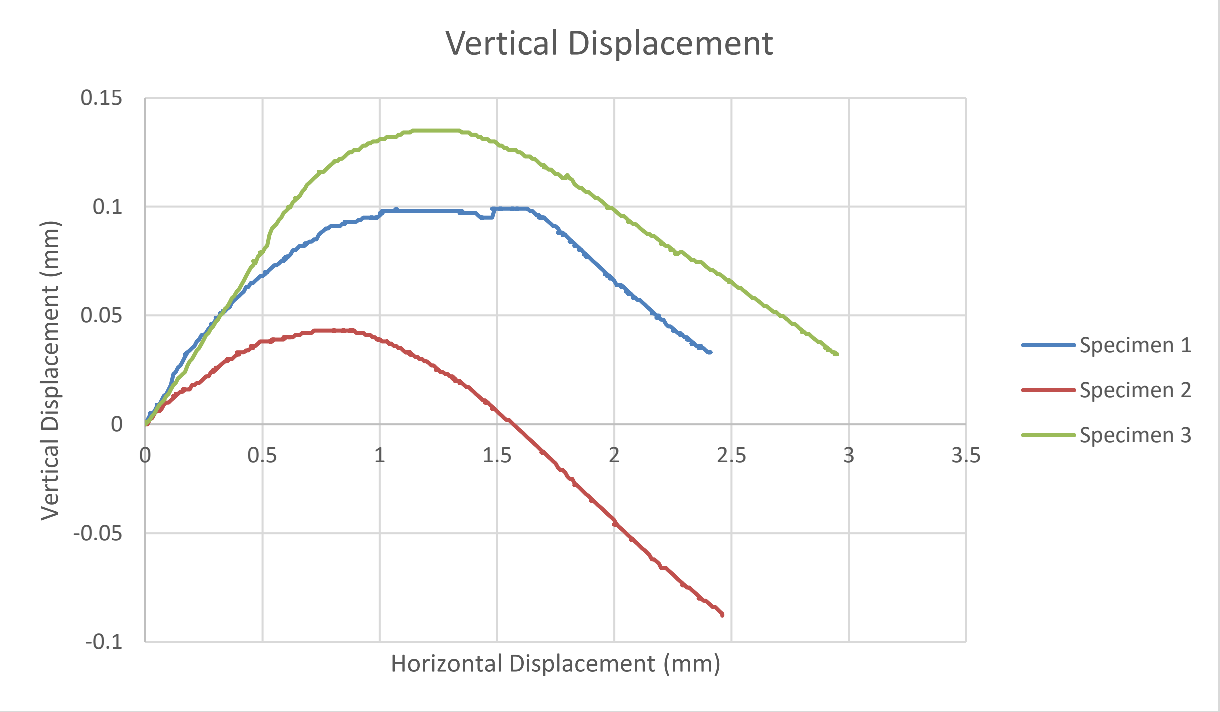
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference Jobfile Client	 SWG00088 Zutari	Test Date Sample Borehole	14/09/2020 E_TP14_0.0-1.7m Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	37.4
Cohesion (c)	(kPa)	0.28





STEYN-WILSON GEOTECHNICAL	Test Method BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference	Test Date	14/09/2020
	Jobfile SWG00088	Sample	E_TP14_0.0-1.7m
	Client Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC

Direct Shear Test

Initial Sample Details

		Specimen 1	Specimen 2	Specimen 3
Height	(mm)	20.0	20.0	20.0
Diameter	(mm)	60.0	60.0	60.0
Mass	(g)	123.4	123.6	123.5
Moisture	(%)	10.4	10.4	10.4
Dry Density	(Mg/m^3)	1.98	1.98	1.98
Bulk Density	(Mg/m^3)	2.18	2.19	2.18
Void Ratio		0.310	0.308	0.309
Particle Density	(Mg/m^3)	2.59		
Sample Method		Bag		
Disturbed/Undisturbed		Disturbed		
Remoulded Desity	(Mg/m^3)	98% (1.98)		

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3
Vertical Displacement	(mm)	0.245	0.357	0.363
Void Ratio After Consolidation		0.294	0.285	0.285

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3
Normal Stress	(kPa)	50	100	150
Peak Shear Stress	(kPa)	46.0	80.6	120.6
Horizontal Strain at Failure	(mm)	2.1	2.2	2.4
Verical Stain at Failure	(mm)	0.053	0.177	0.248
Rate of Shear	(mm/min)	0.027	0.030	0.400
Friction Angle (ϕ)	(°)	36.7		
Cohesion (c)	(kPa)	7.96		

Final Sample Details

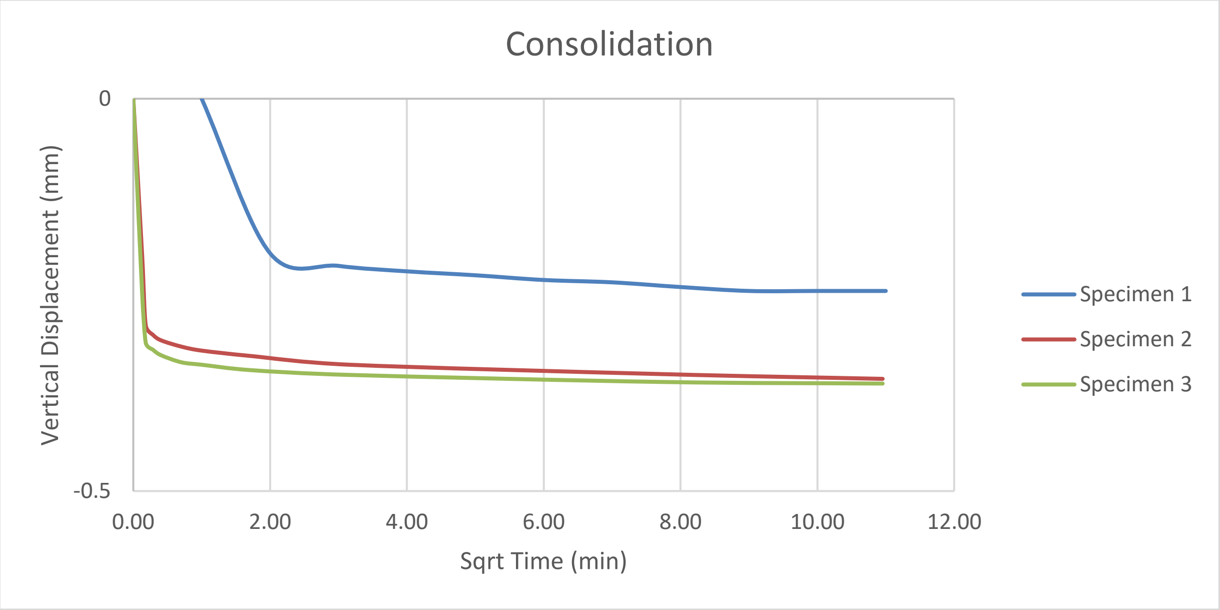
		Specimen 1	Specimen 2	Specimen 3
Mass	(g)	121.0	123.9	123.2
Moisture	(%)	15.0	15.0	14.3
Void Ratio		0.291	0.273	0.269

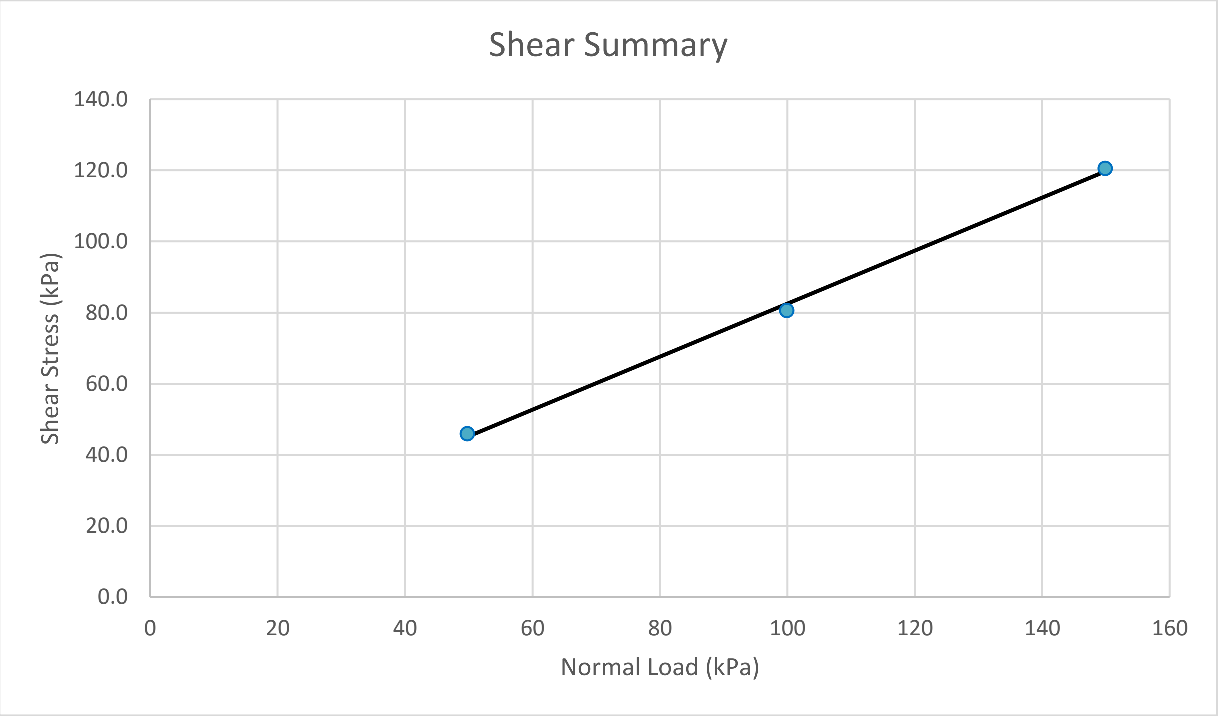
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	14/09/2020
	Jobfile	SWG00088	Sample	E_TP15_0.0-1.4m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	36.7
Cohesion (c)	(kPa)	7.96



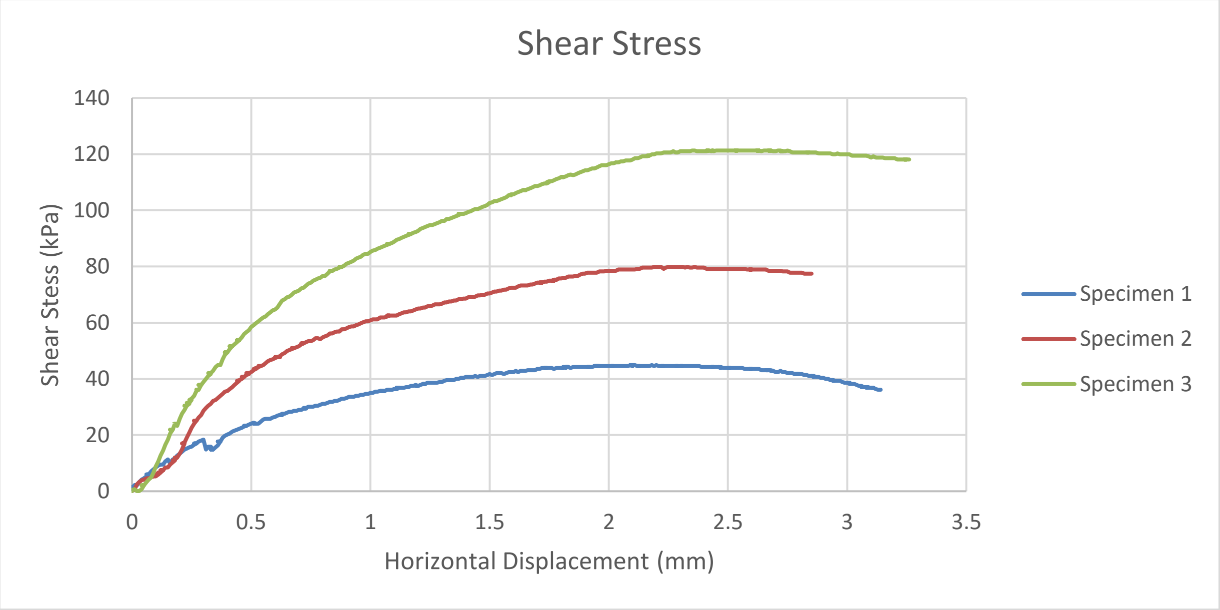


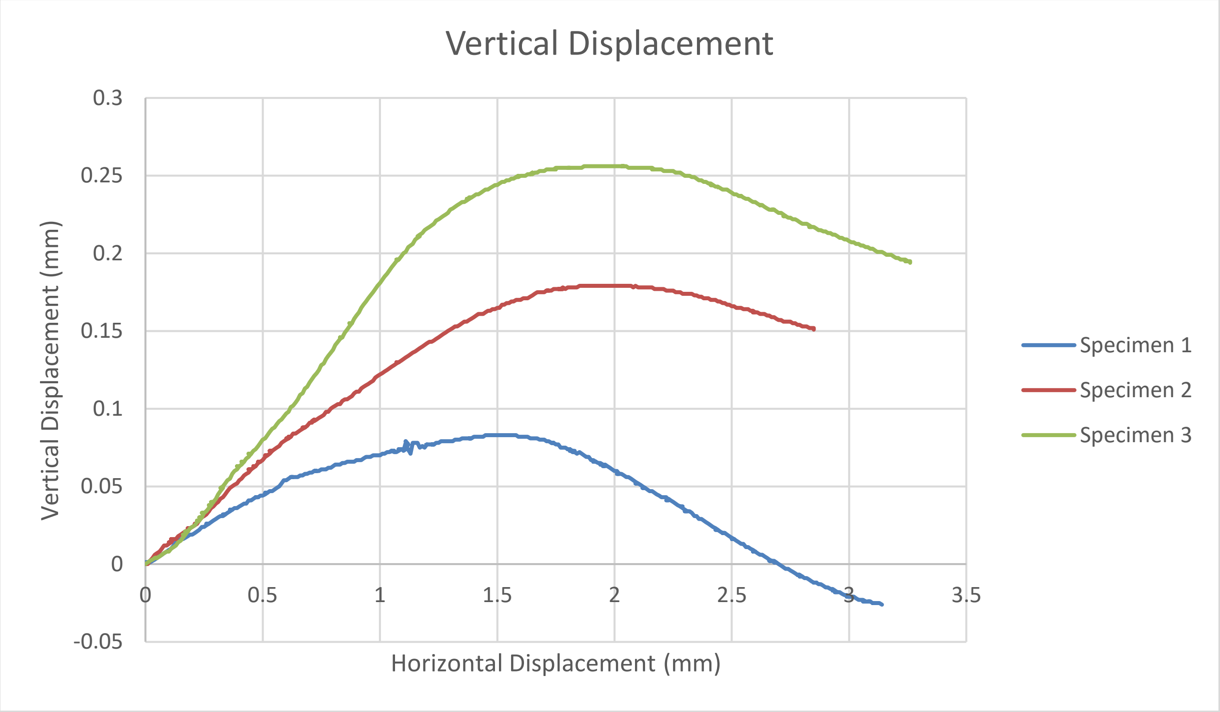
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	14/09/2020
	Jobfile	SWG00088	Sample	E_TP15_0.0-1.4m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	36.7
Cohesion (c)	(kPa)	7.96





STEYN-WILSON GEOTECHNICAL

Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
Site Reference		Test Date	14/09/2020
Jobfile	SWG00088	Sample	E_TP15_0.0-1.4m
Client	Zutari	Borehole	Clanwilliam Bridging Study
Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Initial Sample Details

		Specimen 1	Specimen 2	Specimen 3
Height	(mm)	20.0	20.0	20.0
Diameter	(mm)	60.0	60.0	60.0
Mass	(g)	105.1	105.2	105.1
Moisture	(%)	10.4	10.4	10.4
Dry Density	(Mg/m^3)	1.68	1.69	1.68
Bulk Density	(Mg/m^3)	1.86	1.86	1.86
Void Ratio		0.544	0.543	0.544
Particle Density	(Mg/m^3)	2.60		
Sample Method		Bag		
Disturbed/Undisturbed		Disturbed		
Remoulded Desity	(Mg/m^3)	1.68 (98%)		

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3
Vertical Displacement	(mm)	0.137	0.228	0.320
Void Ratio After Consolidation		0.534	0.525	0.520

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3
Normal Stress	(kPa)	50	100	142
Peak Shear Stress	(kPa)	39.6	76.0	105.7
Horizontal Strain at Failure	(mm)	1.9	1.9	1.6
Verical Stain at Failure	(mm)	0.063	0.040	0.019
Rate of Shear	(mm/min)	0.066	0.049	0.053
Friction Angle (ϕ)	(°)	35.6		
Cohesion (c)	(kPa)	4.05		

Final Sample Details

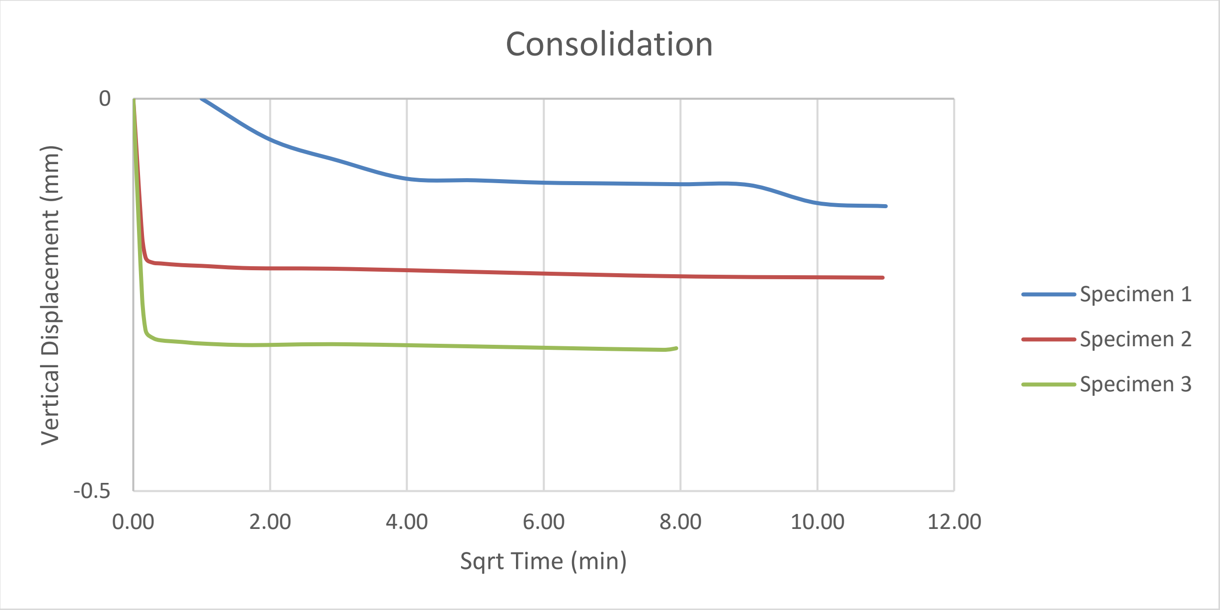
		Specimen 1	Specimen 2	Specimen 3
Mass	(g)	106.3	107.8	106.9
Moisture	(%)	19.7	19.4	20.2
Void Ratio		0.529	0.522	0.518

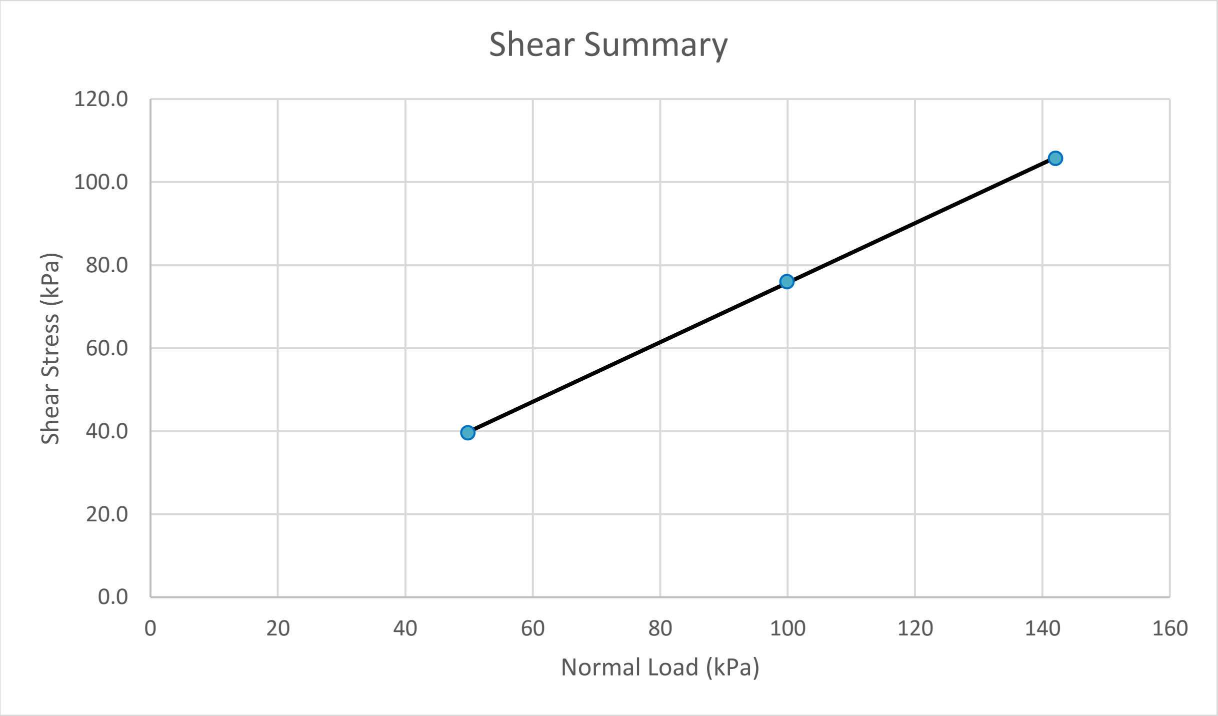
STEYN-WILSON GEOTECHNICAL				
	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	09/09/2020
	Jobfile	SWG00088	Sample	E_TP24 ADD_0.0-2.2m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	35.6
Cohesion (c)	(kPa)	4.05



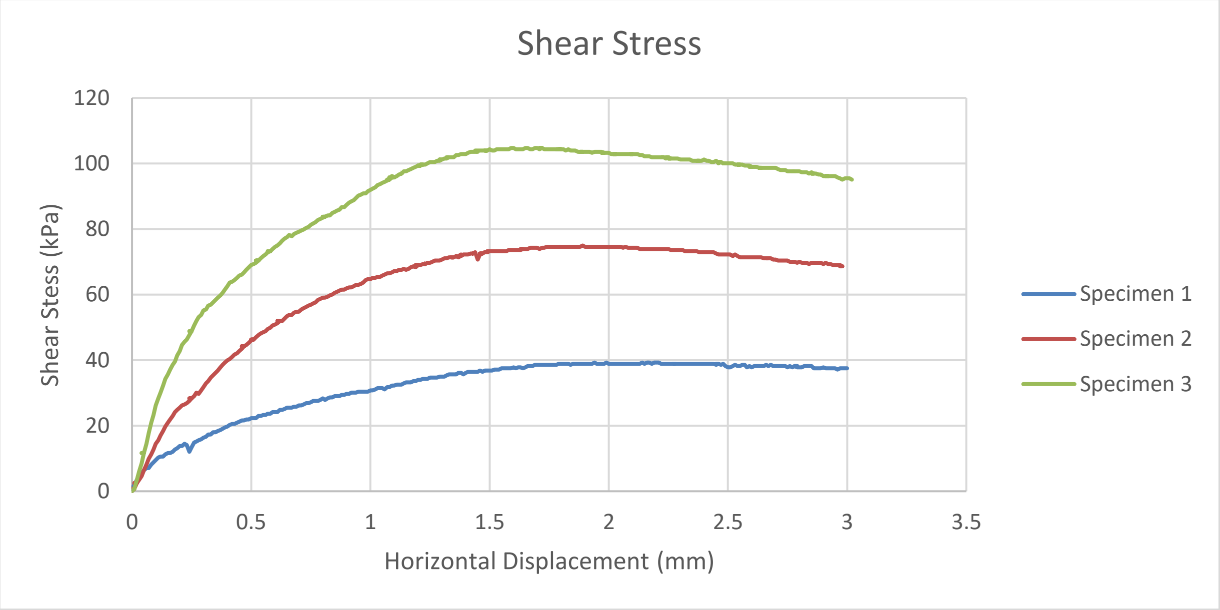


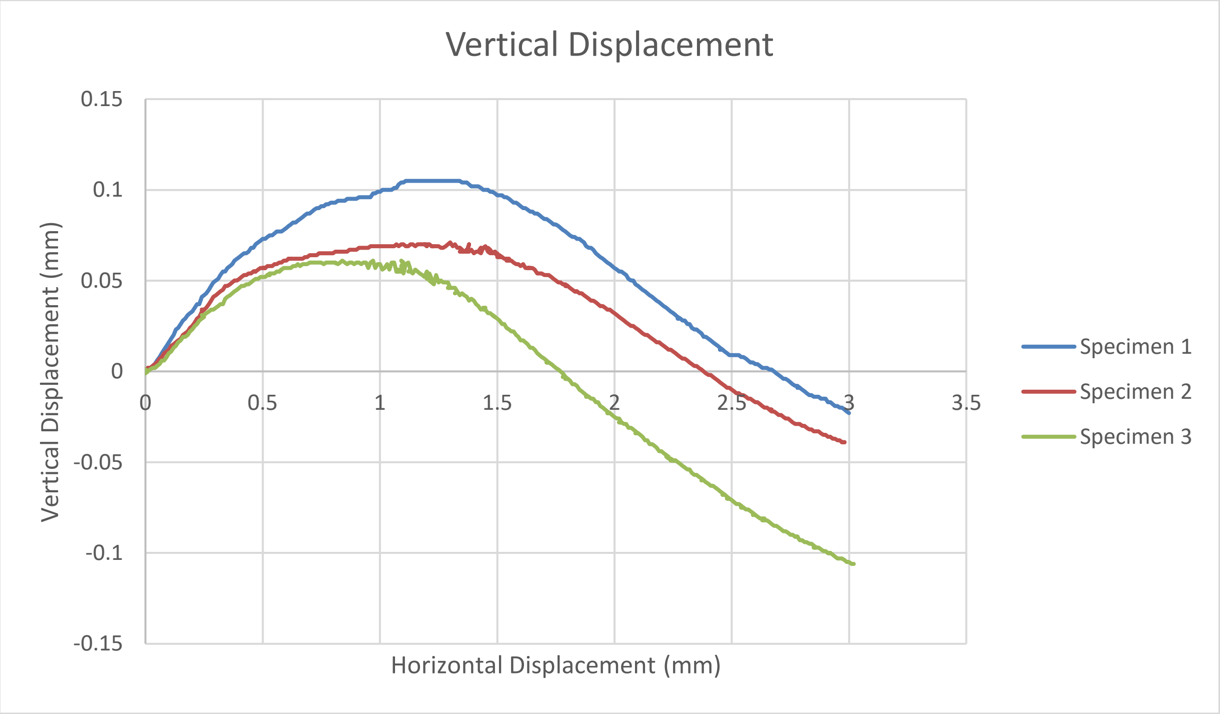
STEYN-WILSON GEOTECHNICAL	Test Method BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech
	Site Reference Jobfile SWG00088 Client Zutari	Test Date 09/09/2020 Sample E_TP24 ADD_0.0-2.2m Borehole Clanwilliam Bridging Study
	Operator:FC Checked: FC	Approved: FC

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	35.6
Cohesion (c)	(kPa)	4.05





STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	09/09/2020
	Jobfile	SWG00088	Sample	E_TP24 ADD_0.0-2.2m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Initial Sample Details

		Specimen 1	Specimen 2	Specimen 3
Height	(mm)	20.0	20.0	20.0
Diameter	(mm)	60.0	60.0	60.0
Mass	(g)	104.8	104.9	104.7
Moisture	(%)	10.5	10.5	10.5
Dry Density	(Mg/m^3)	1.68	1.68	1.68
Bulk Density	(Mg/m^3)	1.85	1.86	1.85
Void Ratio		0.538	0.537	0.540
Particle Density	(Mg/m^3)	2.58		
Sample Method		Bag		
Disturbed/Undisturbed		Disturbed		
Remoulded Desity	(Mg/m^3)			

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3
Vertical Displacement	(mm)	0.210	0.249	0.325
Void Ratio After Consolidation		0.522	0.518	0.515

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3
Normal Stress	(kPa)	50	100	150
Peak Shear Stress	(kPa)	37.1	73.9	93.4
Horizontal Strain at Failure	(mm)	1.0	1.3	2.5
Verical Stain at Failure	(mm)	0.035	-0.003	0.243
Rate of Shear	(mm/min)	0.055	0.041	0.045
Friction Angle (ϕ)	(°)	34.2		
Cohesion (c)	(kPa)	2.00		

Final Sample Details

		Specimen 1	Specimen 2	Specimen 3
Mass	(g)	103.5	106.1	104.4
Moisture	(%)	18.6	17.9	18.1
Void Ratio		0.519	0.518	0.496

STEYN-WILSON
GEOTECHNICAL

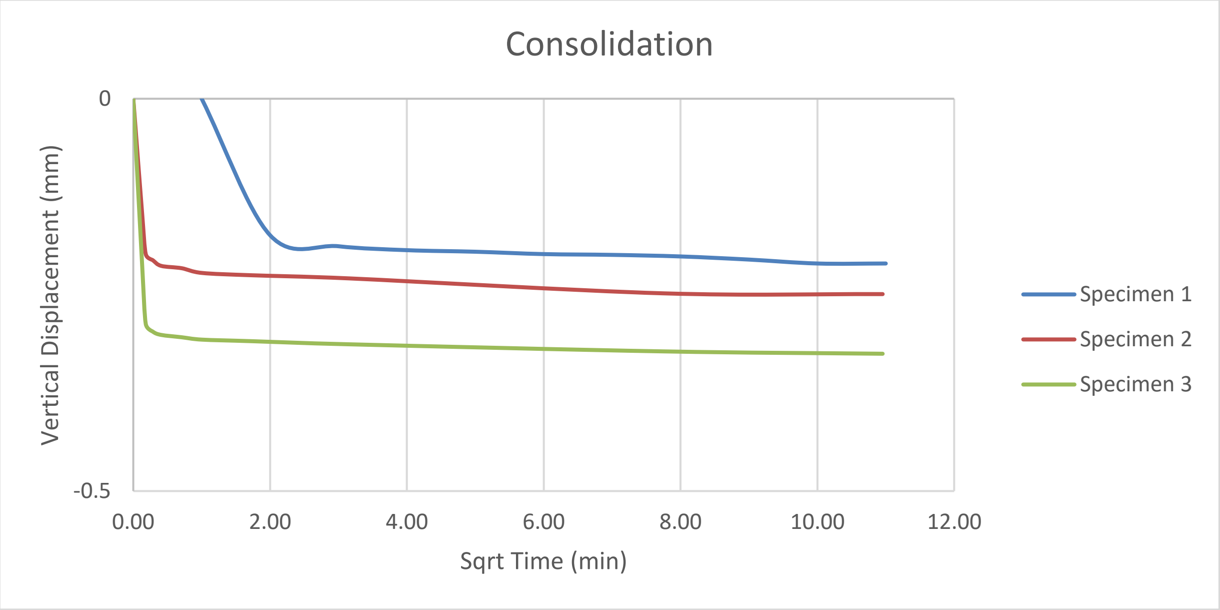
Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
Site Reference		Test Date	15/09/2020
Jobfile	SWG00088	Sample	E TP53_0.0-1.5m
Client	Zutari	Borehole	Clanwilliam Bridging Study

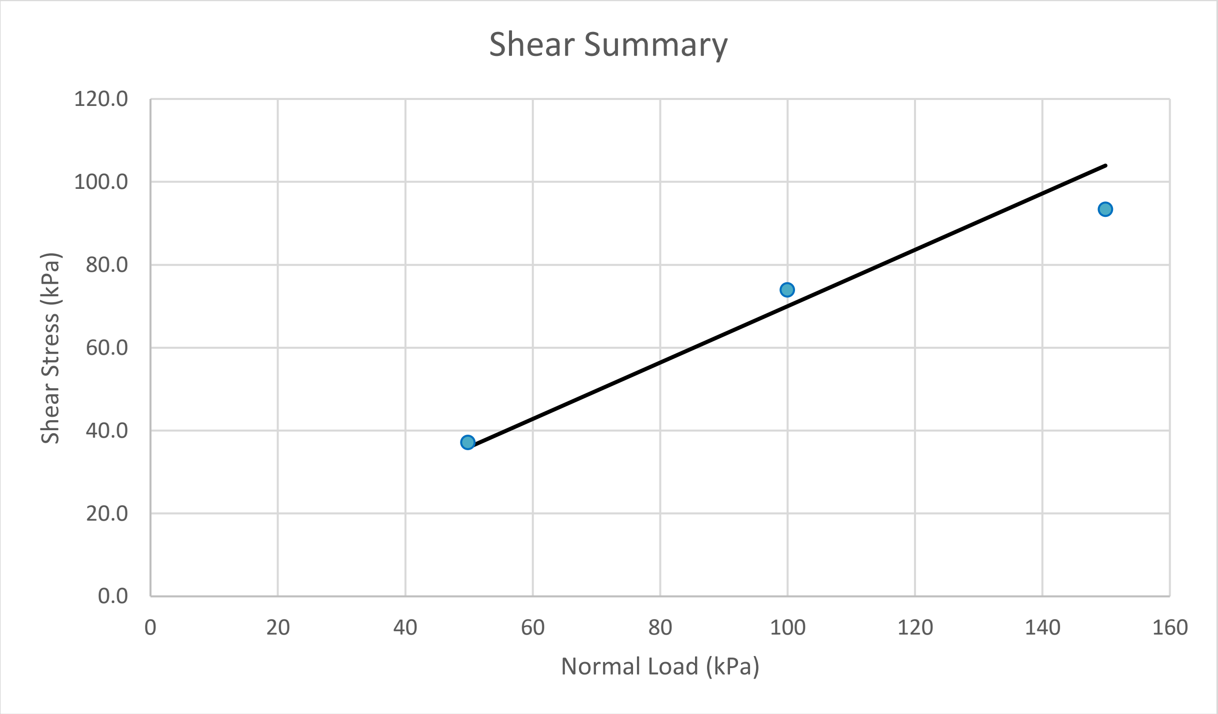
Operator:FC Checked: FC Approved: FC

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	34.2
Cohesion (c)	(kPa)	2.00



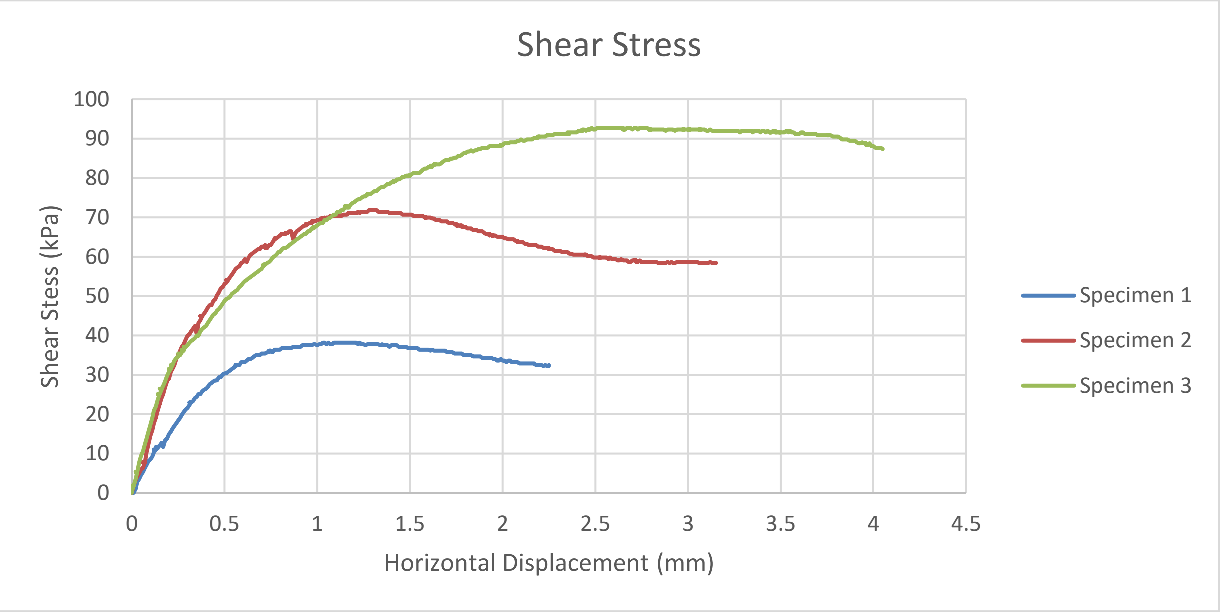


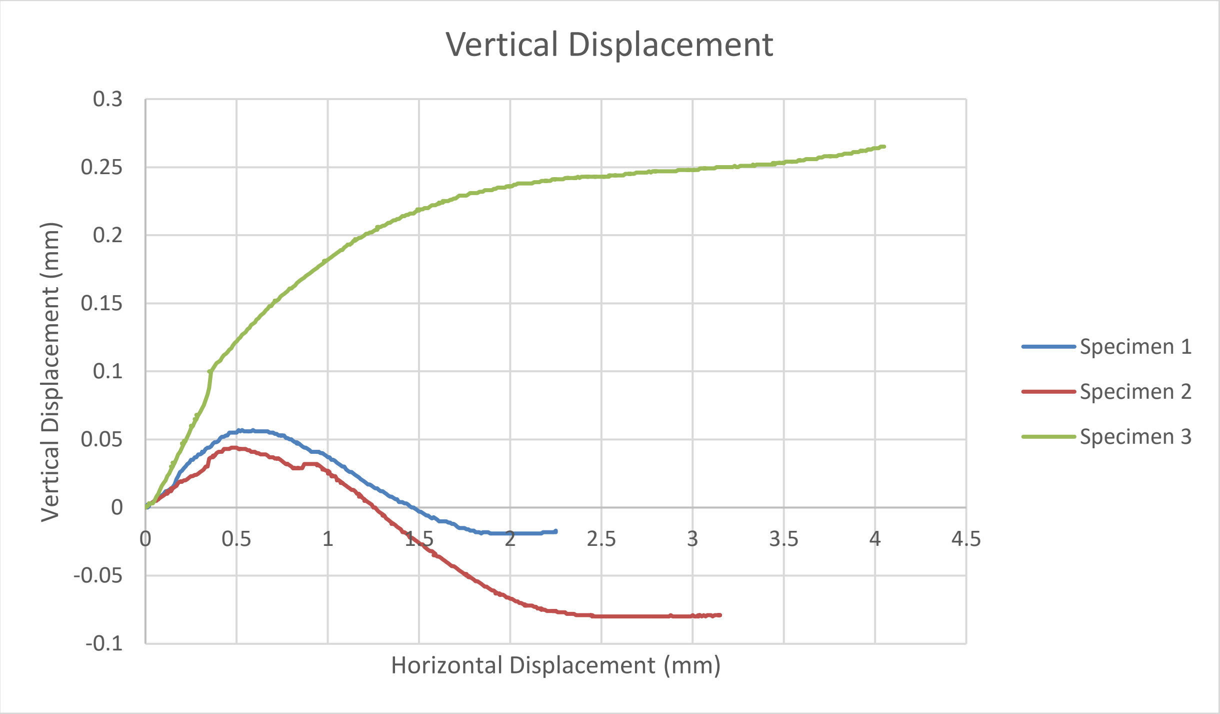
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	15/09/2020
	Jobfile	SWG00088	Sample	E TP53_0.0-1.5m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	34.2
Cohesion (c)	(kPa)	2.00





STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	15/09/2020
	Jobfile	SWG00088	Sample	E TP53_0.0-1.5m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Initial Sample Details

		Specimen 1	Specimen 2	Specimen 3
Height	(mm)	20.0	20.0	20.0
Diameter	(mm)	60.0	60.0	60.0
Mass	(g)	102.0	102.1	102.0
Moisture	(%)	11.3	11.3	11.3
Dry Density	(Mg/m^3)	1.62	1.62	1.62
Bulk Density	(Mg/m^3)	1.80	1.81	1.80
Void Ratio		0.604	0.603	0.604
Particle Density	(Mg/m^3)		2.60	
Sample Method			Bag	
Disturbed/Undisturbed			Disturbed	
Remoulded Desity	(Mg/m^3)		98% (1.62)	

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3
Vertical Displacement	(mm)	0.158	0.304	1.124
Void Ratio After Consolidation		0.592	0.578	0.514

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3
Normal Stress	(kPa)	50	100	150
Peak Shear Stress	(kPa)	32.2	57.6	86.3
Horizontal Strain at Failure	(mm)	4.3	8.8	7.0
Verical Stain at Failure	(mm)	0.275	0.717	0.543
Rate of Shear	(mm/min)	0.074	0.038	0.072
Friction Angle (ϕ)	(°)		28.4	
Cohesion (c)	(kPa)		4.73	

Final Sample Details

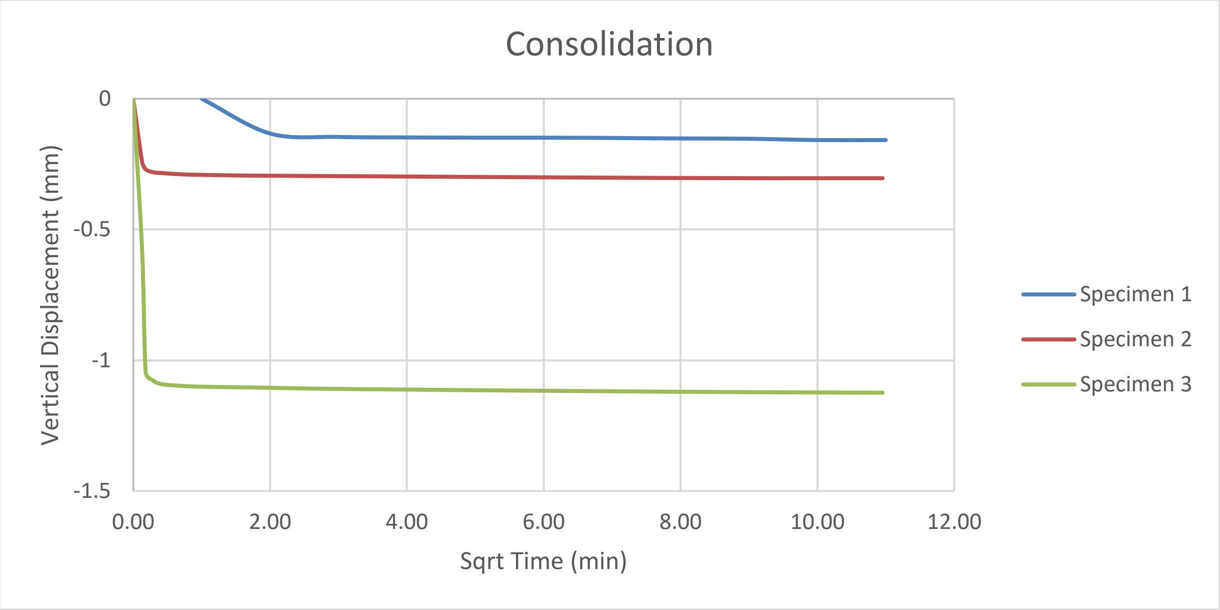
		Specimen 1	Specimen 2	Specimen 3
Mass	(g)	103.1	97.7	102.2
Moisture	(%)	17.6	18.0	16.9
Void Ratio		0.570	0.521	0.471

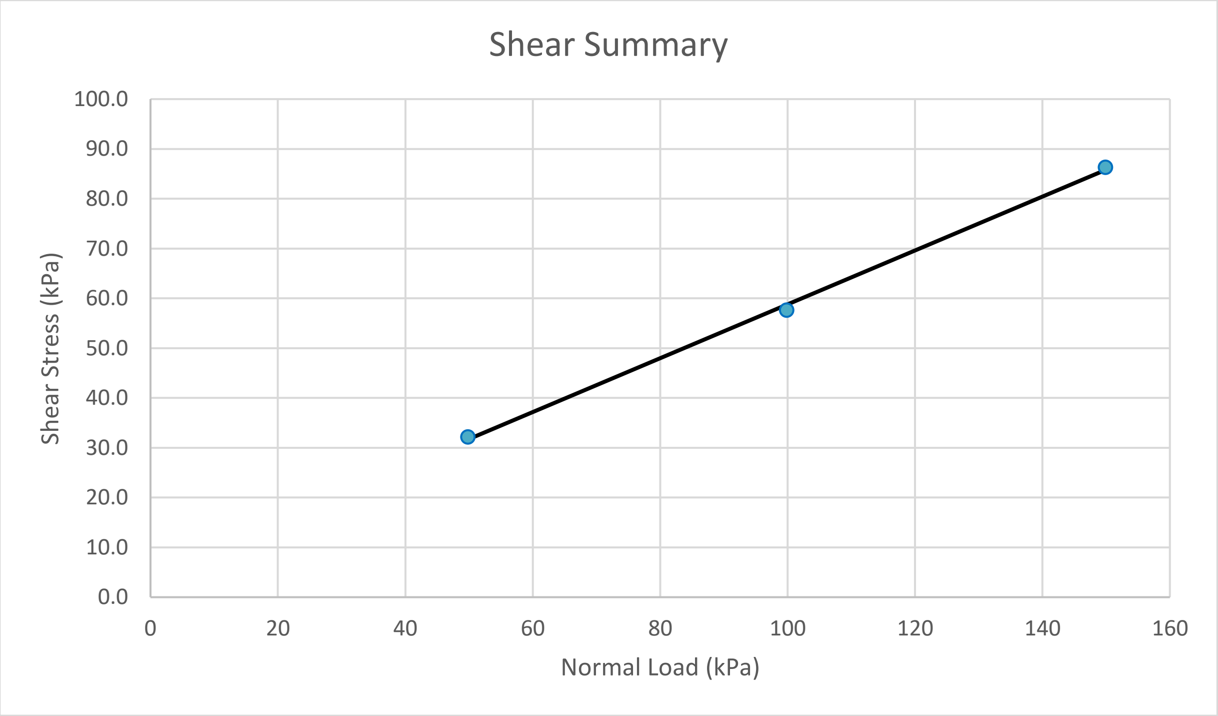
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	16/09/2020
	Jobfile	SWG00088	Sample	E TP33_0.0-1.6m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	28.4
Cohesion (c)	(kPa)	4.73



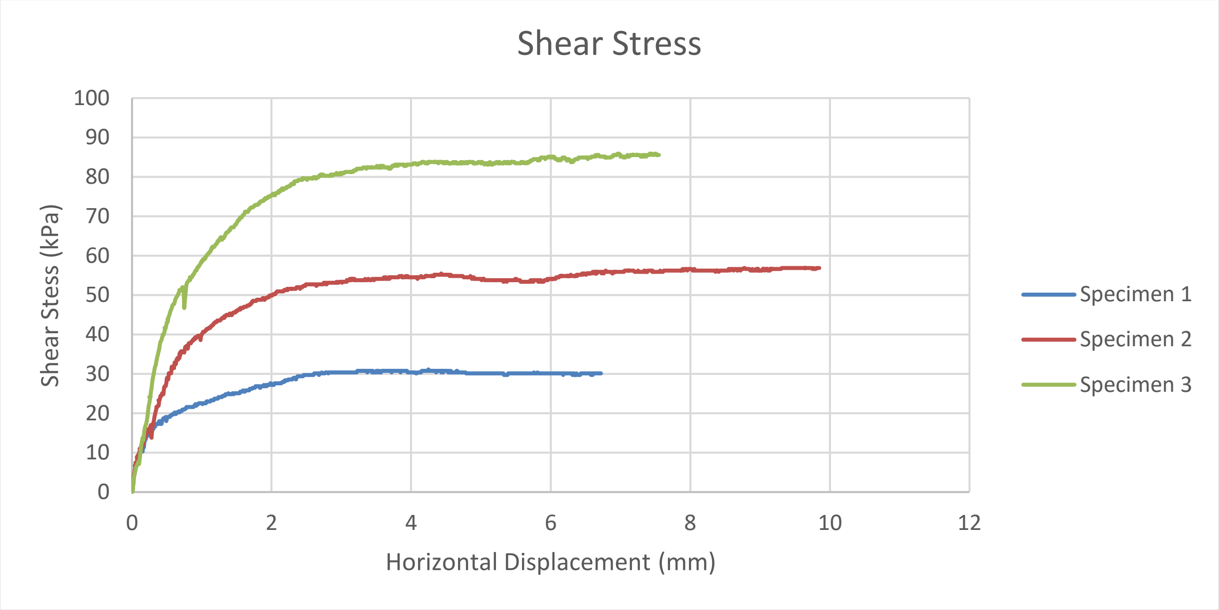


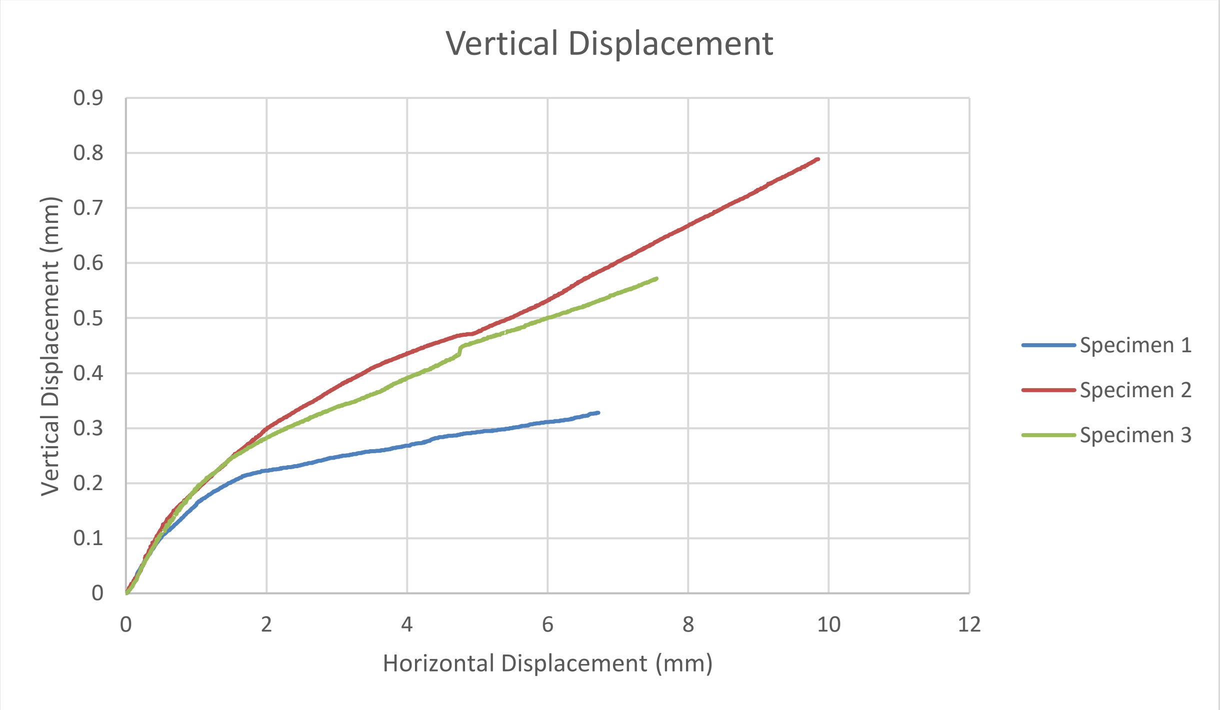
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	16/09/2020
	Jobfile	SWG00088	Sample	E TP33_0.0-1.6m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	28.4
Cohesion (c)	(kPa)	4.73





STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference Jobfile Client	 SWG00088 Zutari	Test Date Sample Borehole	16/09/2020 E TP33_0.0-1.6m Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Initial Sample Details

		Specimen 1	Specimen 2	Specimen 3
Height	(mm)	20.0	20.0	20.0
Diameter	(mm)	60.0	60.0	60.0
Mass	(g)	102.2	102.2	102.0
Moisture	(%)	11.2	11.2	11.2
Dry Density	(Mg/m^3)	1.63	1.63	1.62
Bulk Density	(Mg/m^3)	1.81	1.81	1.80
Void Ratio		0.587	0.587	0.591
Particle Density	(Mg/m^3)	2.58		
Sample Method		Bag		
Disturbed/Undisturbed		Disturbed		
Remoulded Desity	(Mg/m^3)			

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3
Vertical Displacement	(mm)	0.247	0.298	0.582
Void Ratio After Consolidation		0.568	0.564	0.544

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3
Normal Stress	(kPa)	50	100	141
Peak Shear Stress	(kPa)	32.2	67.2	87.0
Horizontal Strain at Failure	(mm)	2.1	2.4	2.9
Verical Stain at Failure	(mm)	0.090	0.101	0.138
Rate of Shear	(mm/min)	0.030	0.052	0.047
Friction Angle (ϕ)	(°)	31.1		
Cohesion (c)	(kPa)	3.69		

Final Sample Details

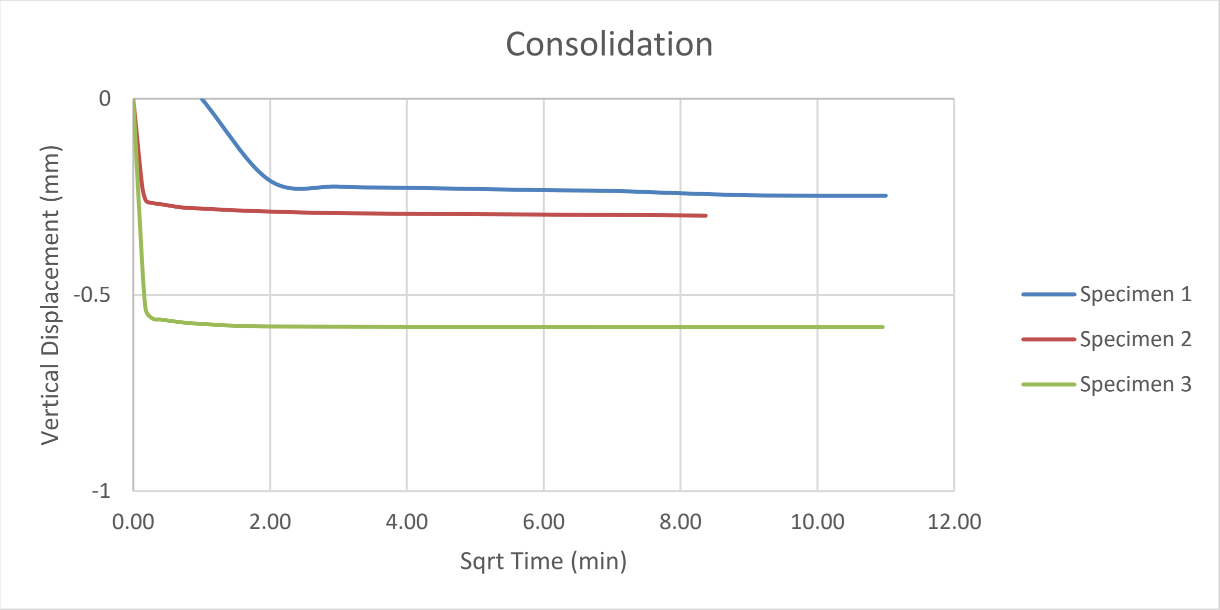
		Specimen 1	Specimen 2	Specimen 3
Mass	(g)	103.9	102.8	99.6
Moisture	(%)	21.1	20.1	21.9
Void Ratio		0.561	0.556	0.533

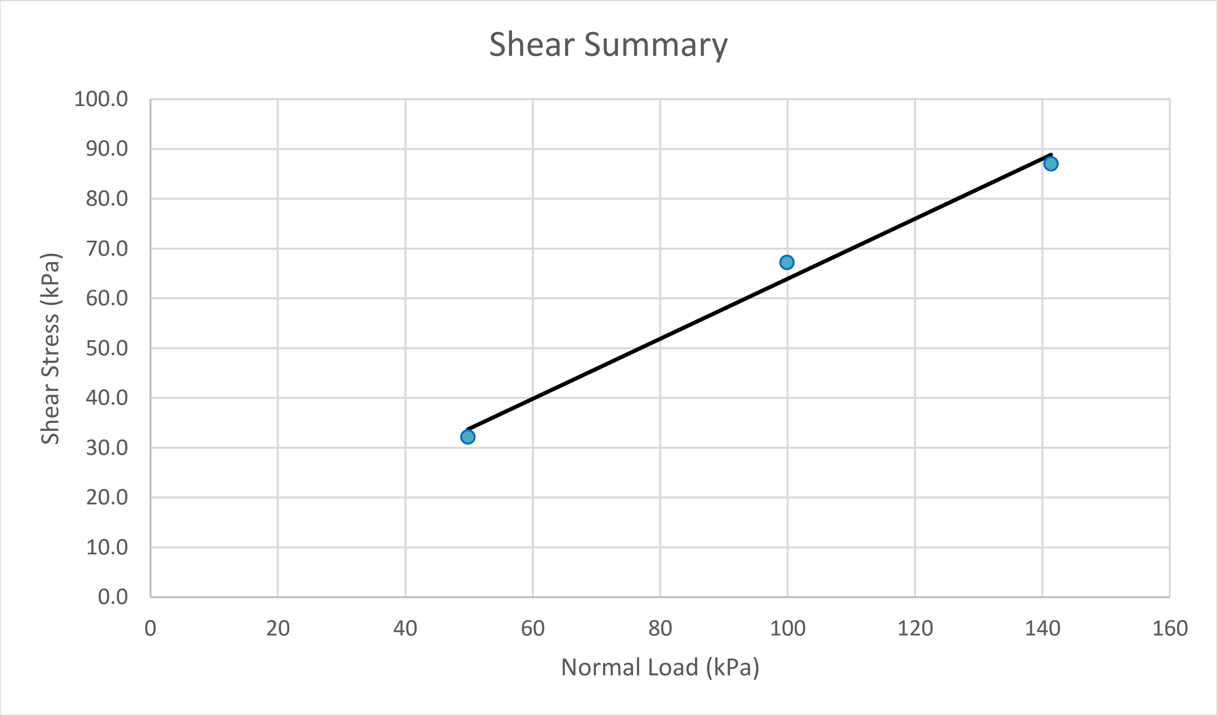
STEYN-WILSON GEOTECHNICAL	Test Method BS1377 - 7: 1990		Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech
	Site Reference		Test Date 12/09/2020
	Jobfile	SWG00088	Sample E_TP38_0.0-0.9m
	Client	Zutari	Borehole Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	31.1
Cohesion (c)	(kPa)	3.69



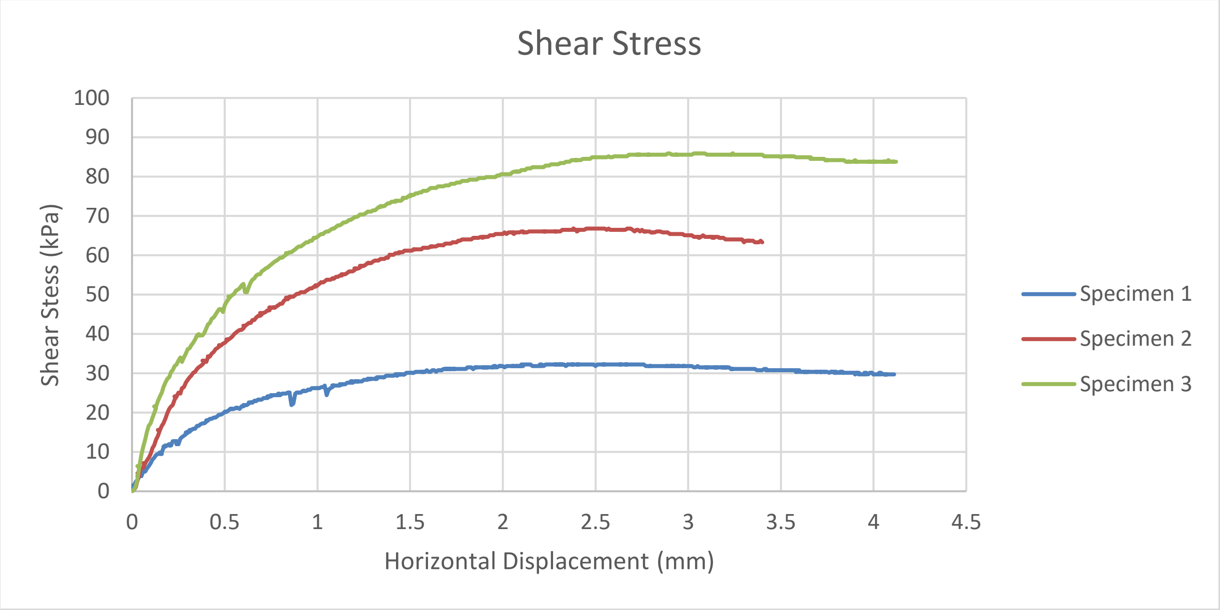


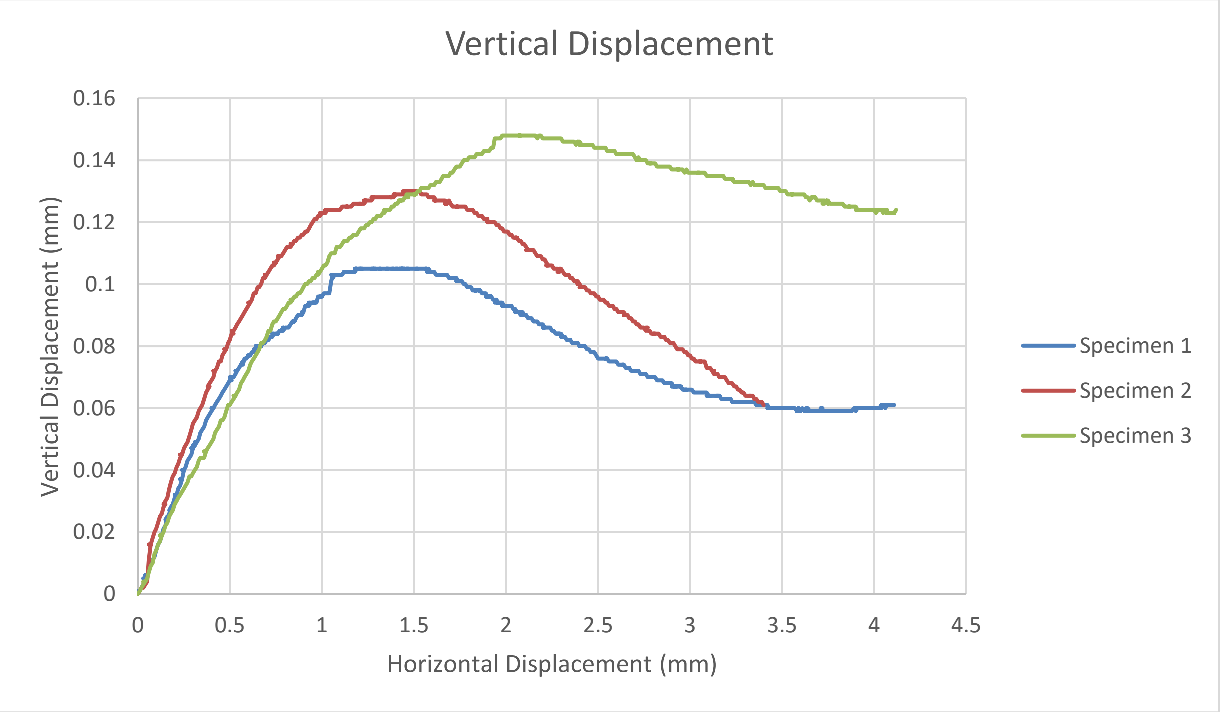
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	12/09/2020
	Jobfile	SWG00088	Sample	E_TP38_0.0-0.9m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	31.1
Cohesion (c)	(kPa)	3.69





STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference Jobfile Client	 SWG00088 Zutari	Test Date Sample Borehole	12/09/2020 E_TP38_0.0-0.9m Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Initial Sample Details

		Specimen 1	Specimen 2	Specimen 3
Height	(mm)	20.0	20.0	20.0
Diameter	(mm)	60.0	60.0	60.0
Mass	(g)	114.8	114.7	114.6
Moisture	(%)	9.6	9.6	9.6
Dry Density	(Mg/m^3)	1.85	1.85	1.85
Bulk Density	(Mg/m^3)	2.03	2.03	2.03
Void Ratio		0.387	0.389	0.390
Particle Density	(Mg/m^3)		2.57	
Sample Method			Bag	
Disturbed/Undisturbed			Disturbed	
Remoulded Desity	(Mg/m^3)			

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3
Vertical Displacement	(mm)	0.261	0.515	0.600
Void Ratio After Consolidation		0.369	0.353	0.348

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3
Normal Stress	(kPa)	50	100	150
Peak Shear Stress	(kPa)	75.7	115.7	155.6
Horizontal Strain at Failure	(mm)	0.9	1.3	2.0
Verical Stain at Failure	(mm)	-0.103	0.018	-0.032
Rate of Shear	(mm/min)	0.017	0.015	0.024
Friction Angle (ϕ)	(°)		38.6	
Cohesion (c)	(kPa)		35.91	

Final Sample Details

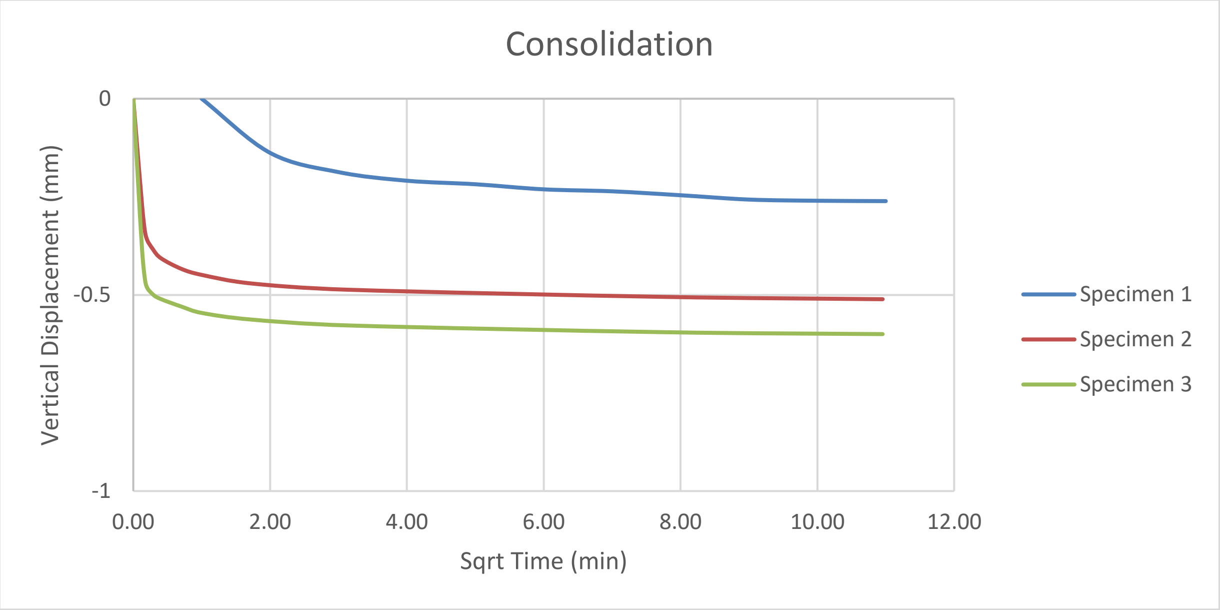
		Specimen 1	Specimen 2	Specimen 3
Mass	(g)	122.6	121.9	124.0
Moisture	(%)	24.6	24.0	25.5
Void Ratio		0.377	0.352	0.350

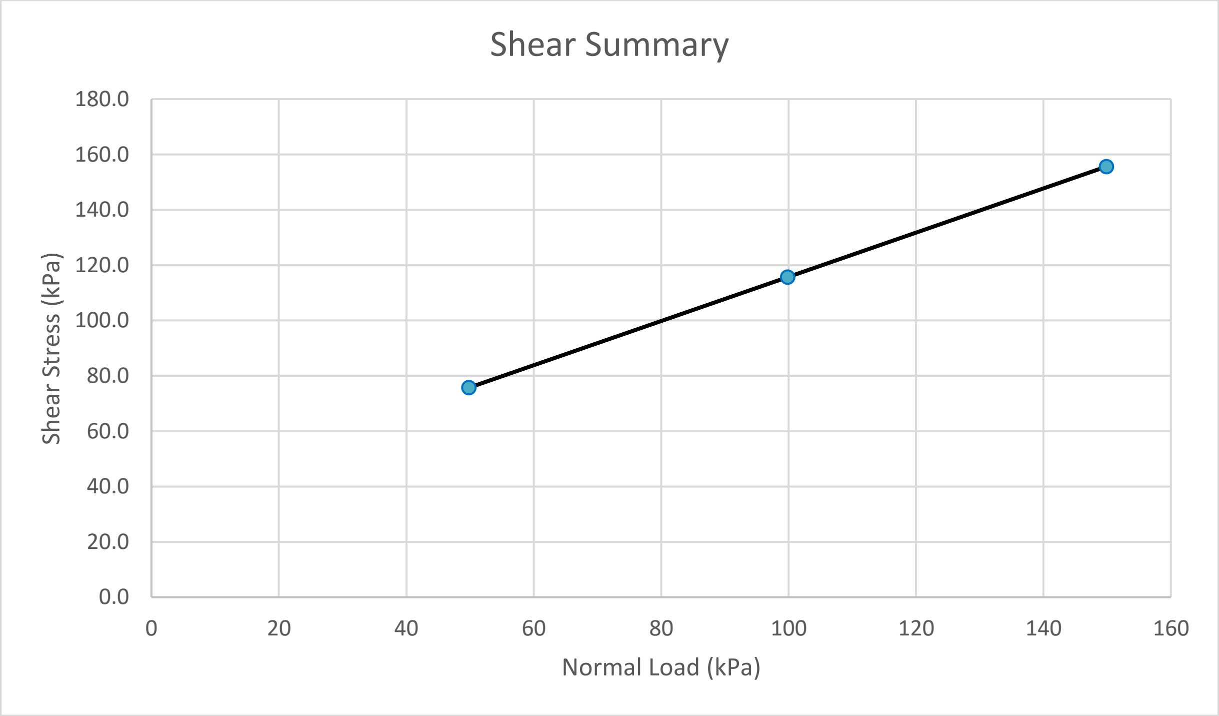
STEYN-WILSON GEOTECHNICAL	Test Method BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference	Test Date	23/09/2020
	Jobfile SWG00088	Sample	E TP45_0.5-1.1m
	Client Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	38.6
Cohesion (c)	(kPa)	35.91



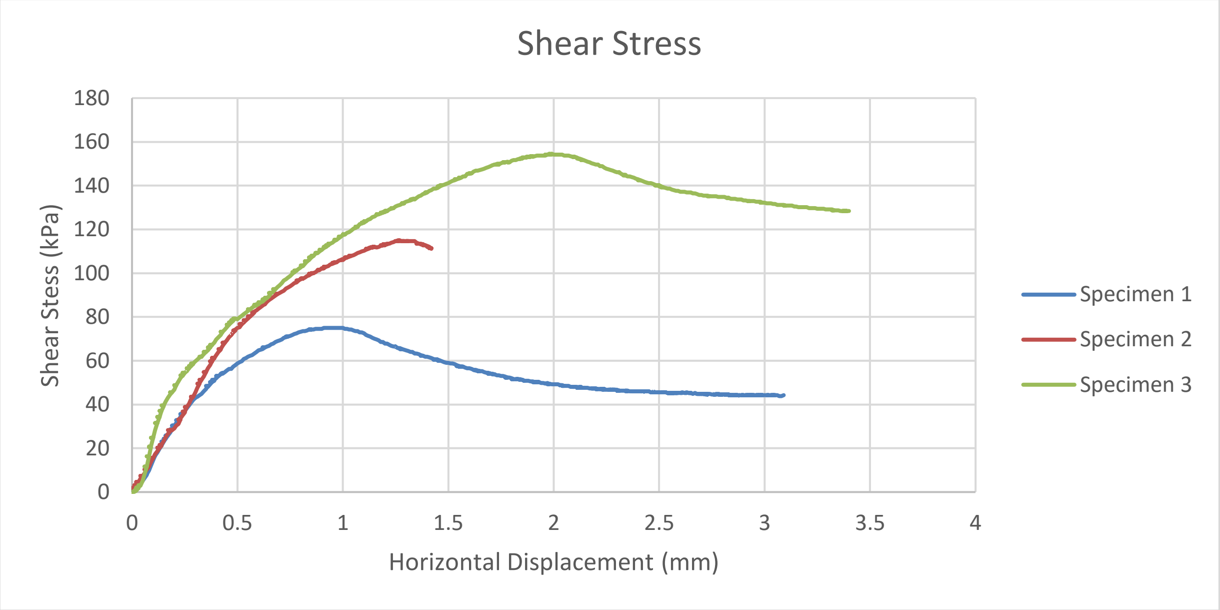


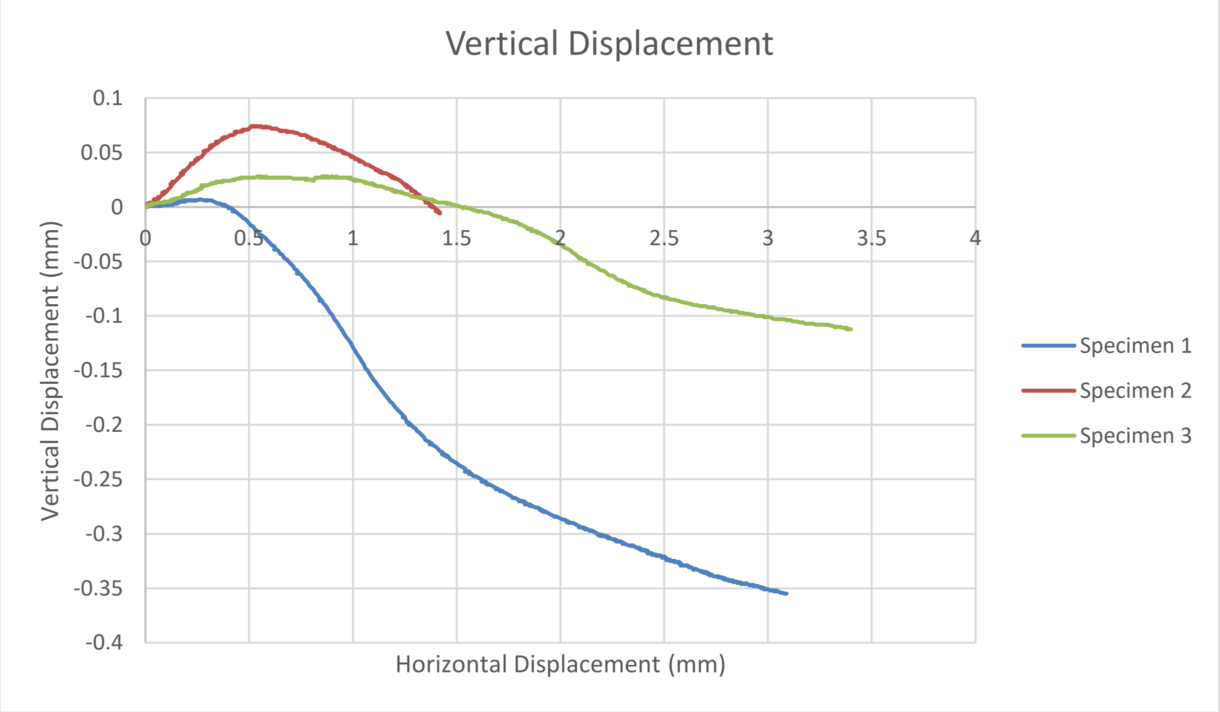
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	23/09/2020
	Jobfile	SWG00088	Sample	E TP45_0.5-1.1m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	38.6
Cohesion (c)	(kPa)	35.91





STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference Jobfile Client	 SWG00088 Zutari	Test Date Sample Borehole	23/09/2020 E TP45_0.5-1.1m Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Initial Sample Details

		Specimen 1	Specimen 2	Specimen 3
Height	(mm)	20.0	20.0	20.0
Diameter	(mm)	60.0	60.0	60.0
Mass	(g)	106.5	106.5	106.7
Moisture	(%)	9.5	9.5	9.5
Dry Density	(Mg/m^3)	1.72	1.72	1.72
Bulk Density	(Mg/m^3)	1.88	1.88	1.89
Void Ratio		0.512	0.512	0.509
Particle Density	(Mg/m^3)	2.60		
Sample Method		Bag		
Disturbed/Undisturbed		Disturbed		
Remoulded Desity	(Mg/m^3)			

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3
Vertical Displacement	(mm)	0.298	0.410	0.525
Void Ratio After Consolidation		0.489	0.481	0.469

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3
Normal Stress	(kPa)	50	100	150
Peak Shear Stress	(kPa)	39.3	78.5	114.9
Horizontal Strain at Failure	(mm)	2.0	1.6	2.1
Verical Stain at Failure	(mm)	0.067	-0.014	0.000
Rate of Shear	(mm/min)	0.049	0.022	0.044
Friction Angle (ϕ)	(°)	37.1		
Cohesion (c)	(kPa)	2.06		

Final Sample Details

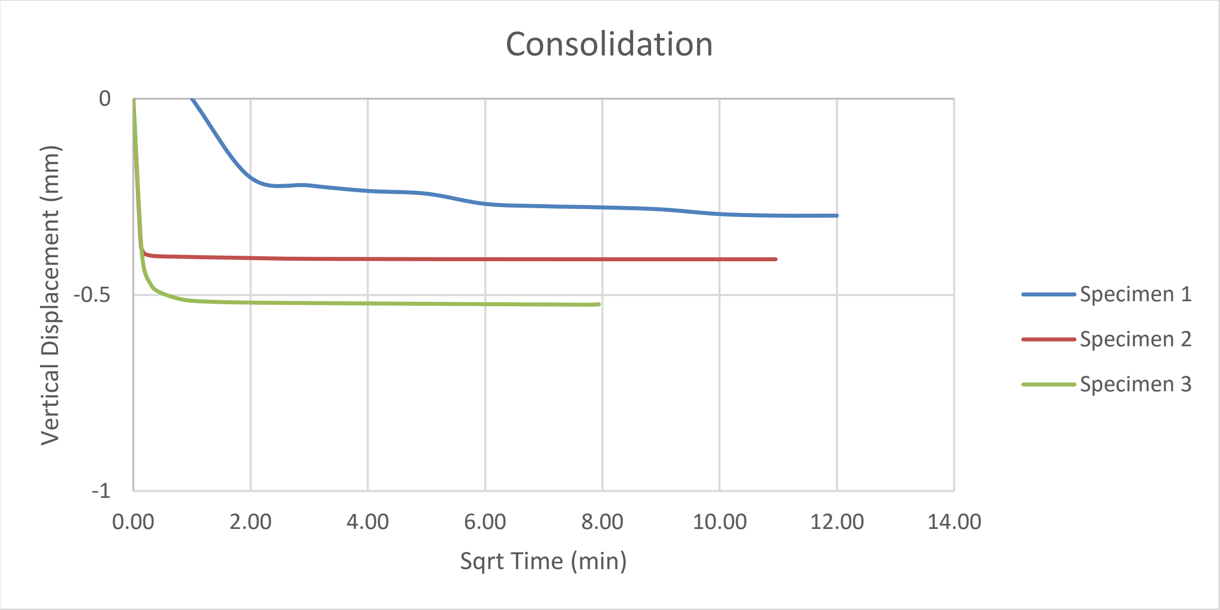
		Specimen 1	Specimen 2	Specimen 3
Mass	(g)	106.1	107.0	109.1
Moisture	(%)	19.8	19.6	19.5
Void Ratio		0.484	0.482	0.469

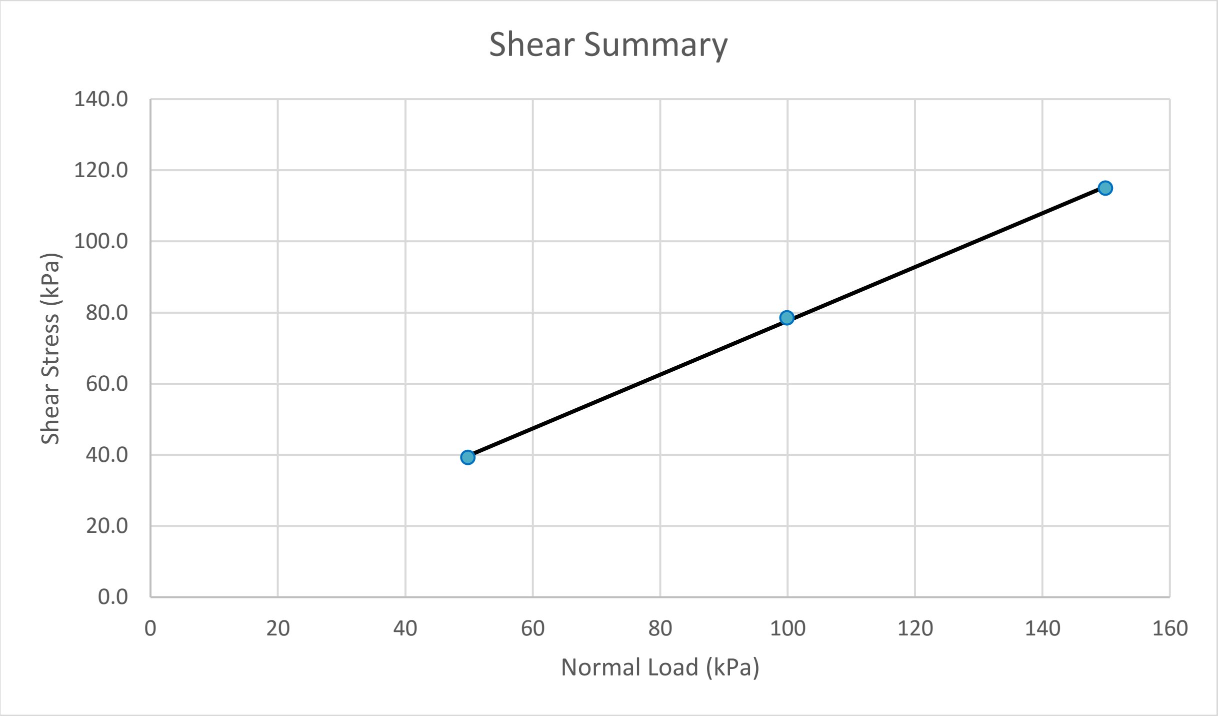
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	17/09/2020
	Jobfile	SWG00088	Sample	E TP46_0.0-0.6m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	37.1
Cohesion (c)	(kPa)	2.06



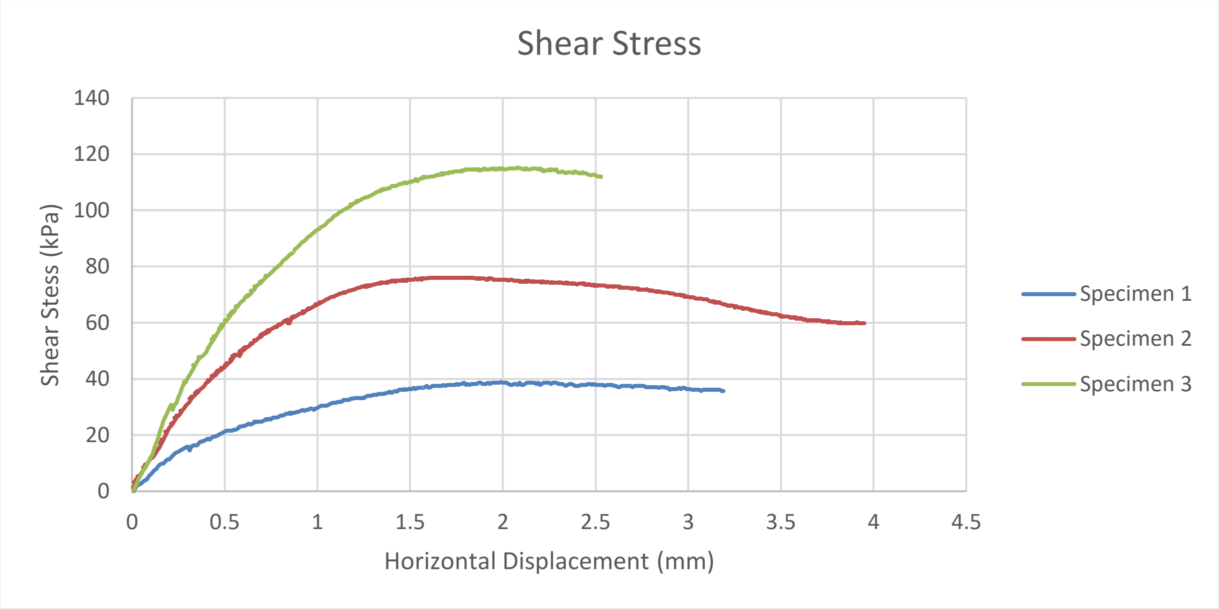


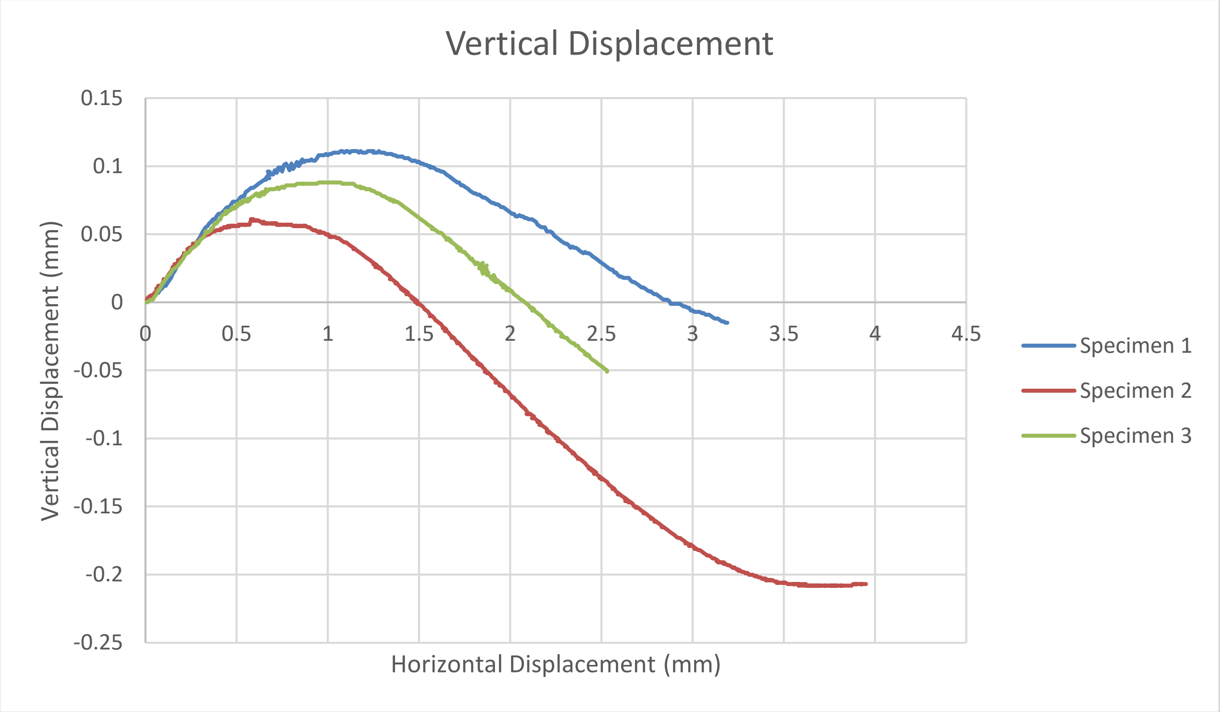
STEYN-WILSON GEOTECHNICAL	Test Method BS1377 - 7: 1990		Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech
	Site Reference		Test Date 17/09/2020
	Jobfile	SWG00088	Sample E TP46_0.0-0.6m
	Client	Zutari	Borehole Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	37.1
Cohesion (c)	(kPa)	2.06





STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference Jobfile Client	 SWG00088 Zutari	Test Date Sample Borehole	17/09/2020 E TP46_0.0-0.6m Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Initial Sample Details

		Specimen 1	Specimen 2	Specimen 3
Height	(mm)	20.0	20.0	20.0
Diameter	(mm)	60.0	60.0	60.0
Mass	(g)	109.0	109.1	108.0
Moisture	(%)	11.1	11.1	11.1
Dry Density	(Mg/m^3)	1.73	1.74	1.72
Bulk Density	(Mg/m^3)	1.93	1.93	1.91
Void Ratio		0.487	0.486	0.501
Particle Density	(Mg/m^3)	2.58		
Sample Method		Bag		
Disturbed/Undisturbed		Disturbed		
Remoulded Desity	(Mg/m^3)	1.73 (98%)		

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3
Vertical Displacement	(mm)	0.210	0.299	0.325
Void Ratio After Consolidation		0.471	0.463	0.476

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3
Normal Stress	(kPa)	50	100	150
Peak Shear Stress	(kPa)	37.1	73.9	93.4
Horizontal Strain at Failure	(mm)	1.0	1.3	2.5
Verical Stain at Failure	(mm)	0.035	-0.003	0.243
Rate of Shear	(mm/min)	0.055	0.041	0.045
Friction Angle (ϕ)	(°)	34.2		
Cohesion (c)	(kPa)	3.00		

Final Sample Details

		Specimen 1	Specimen 2	Specimen 3
Mass	(g)	108.5	106.9	109.5
Moisture	(%)	16.2	17.7	17.1
Void Ratio		0.469	0.464	0.458

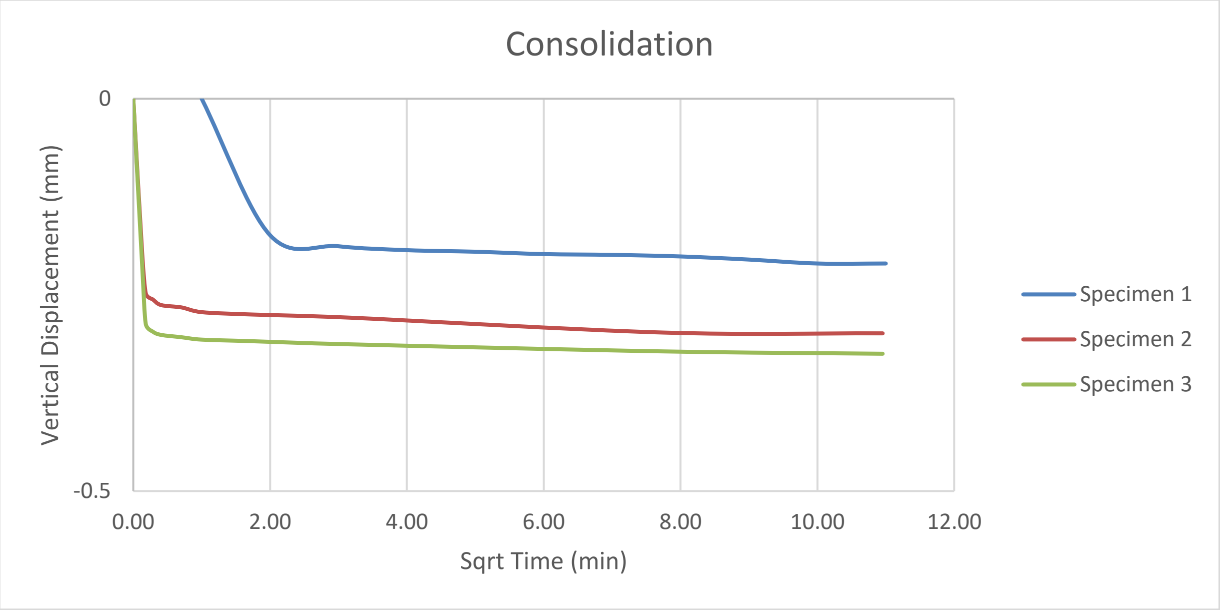
STEYN-WILSON GEOTECHNICAL

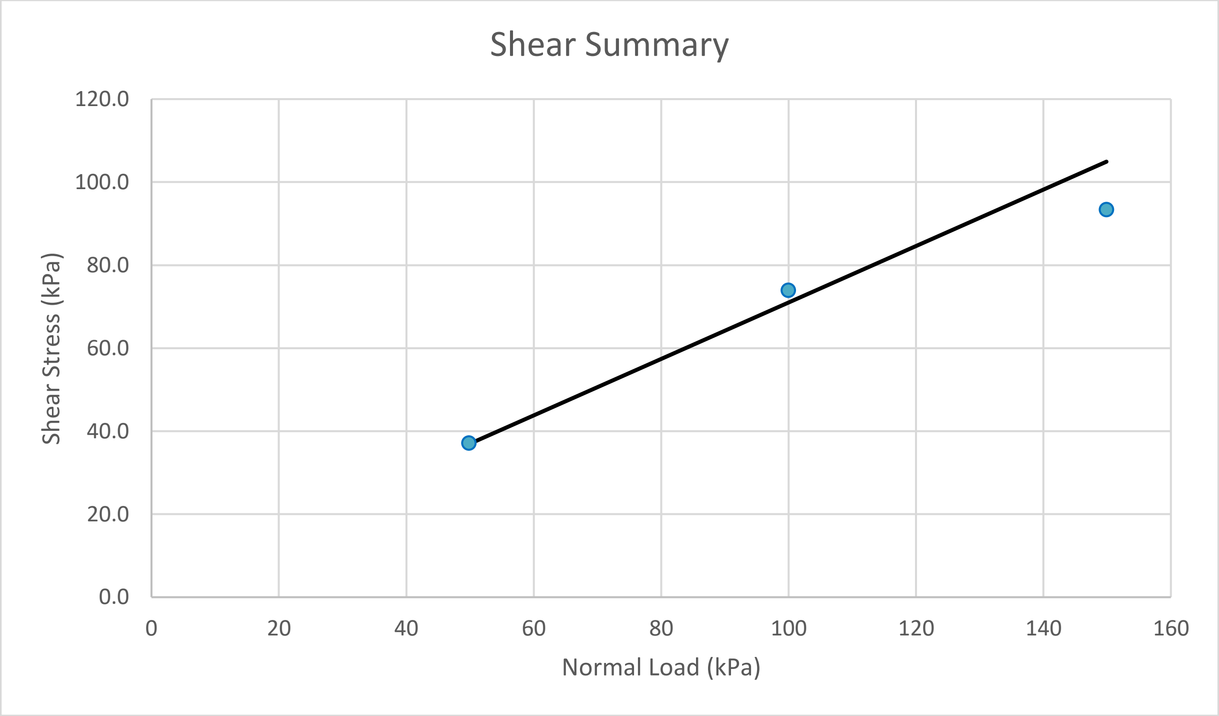
Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
Site Reference		Test Date	20/09/2020
Jobfile	SWG00088	Sample	E TP53_0.0-1.5m
Client	Zutari	Borehole	Clanwilliam Bridging Study
Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	34.2
Cohesion (c)	(kPa)	3.00



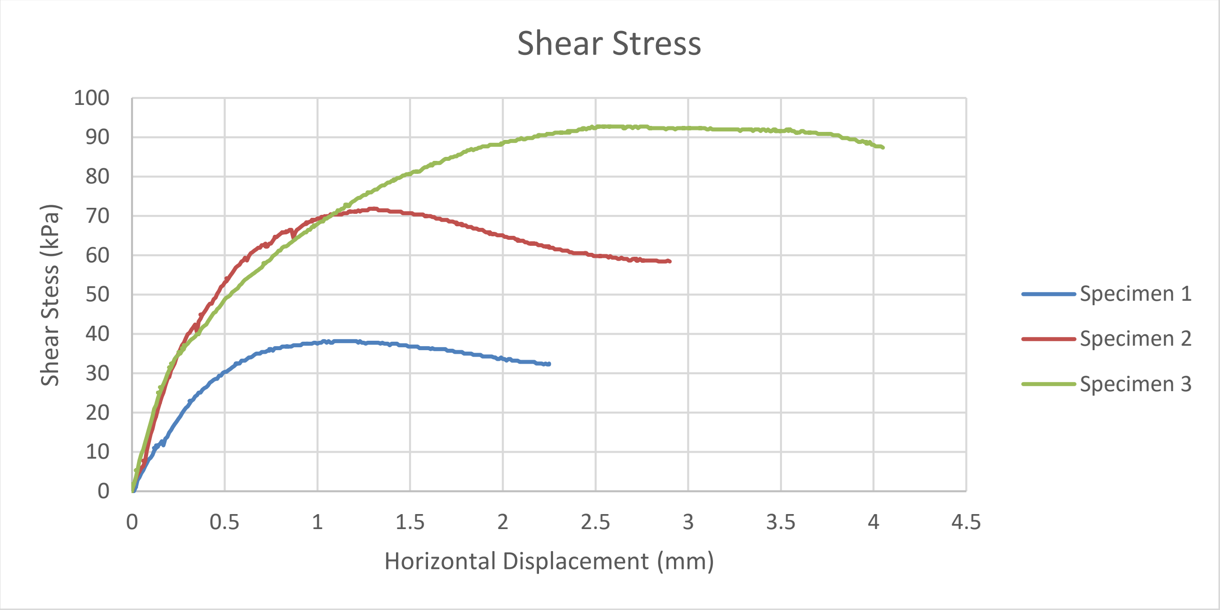


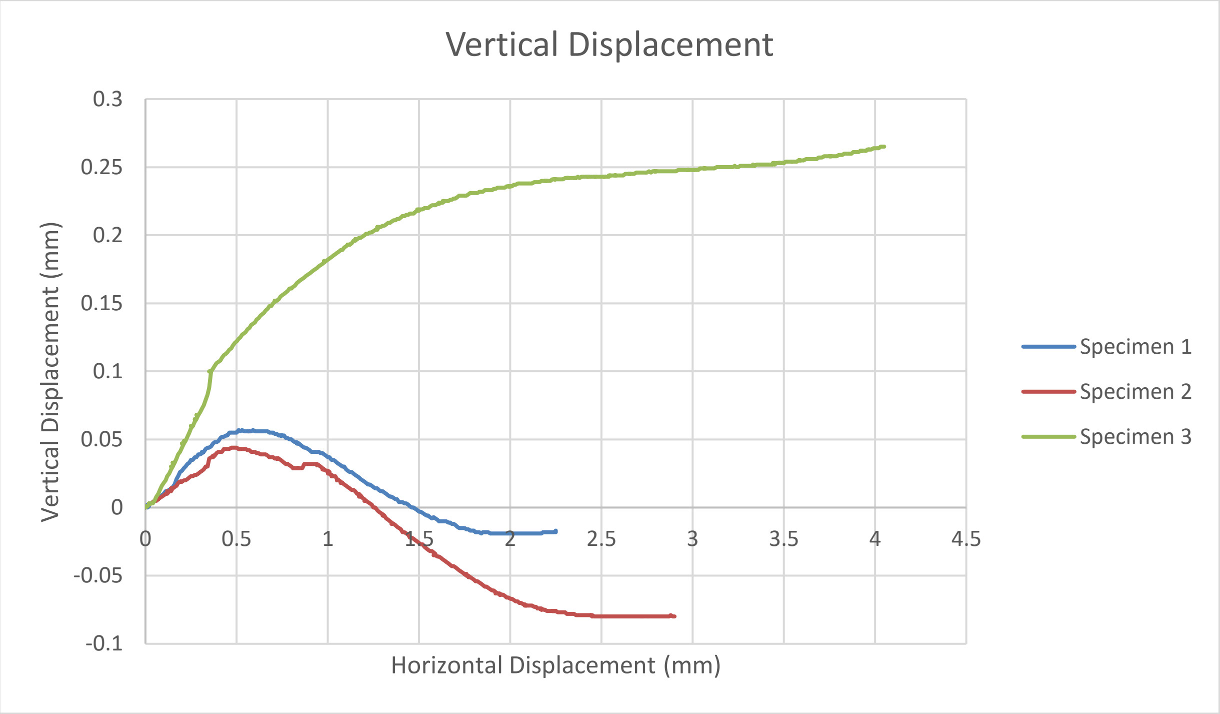
STEYN-WILSON GEOTECHNICAL	Test Method BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference Jobfile SWG00088 Client Zutari	Test Date Sample Borehole	20/09/2020 E TP53_0.0-1.5m Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	34.2
Cohesion (c)	(kPa)	3.00





STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	20/09/2020
	Jobfile	SWG00088	Sample	E TP53_0.0-1.5m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Initial Sample Details

		Specimen 1	Specimen 2	Specimen 3
Height	(mm)	20.0	20.0	20.0
Diameter	(mm)	60.0	60.0	60.0
Mass	(g)	122.5	122.3	122.4
Moisture	(%)	9.6	9.6	9.6
Dry Density	(Mg/m^3)	1.98	1.97	1.97
Bulk Density	(Mg/m^3)	2.17	2.16	2.16
Void Ratio		0.310	0.313	0.311
Particle Density	(Mg/m^3)	2.59		
Sample Method		Bag		
Disturbed/Undisturbed		Disturbed		
Remoulded Desity	(Mg/m^3)	98% (1.97)		

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3
Vertical Displacement	(mm)	0.322	0.516	0.787
Void Ratio After Consolidation		0.289	0.279	0.260

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3
Normal Stress	(kPa)	50	100	149
Peak Shear Stress	(kPa)	55.9	97.6	128.0
Horizontal Strain at Failure	(mm)	1.9	2.1	2.7
Verical Stain at Failure	(mm)	-0.069	0.111	0.434
Rate of Shear	(mm/min)	0.031	0.019	0.030
Friction Angle (ϕ)	(°)	36.1		
Cohesion (c)	(kPa)	21.30		

Final Sample Details

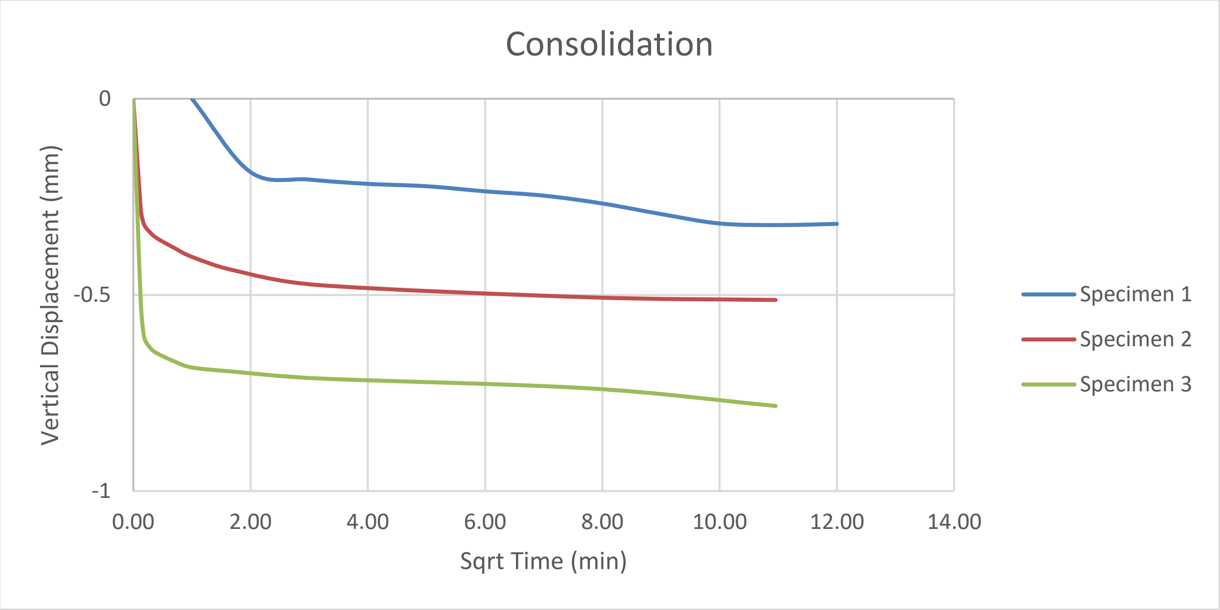
		Specimen 1	Specimen 2	Specimen 3
Mass	(g)	124.7	125.7	124.3
Moisture	(%)	18.3	18.9	17.2
Void Ratio		0.294	0.271	0.231

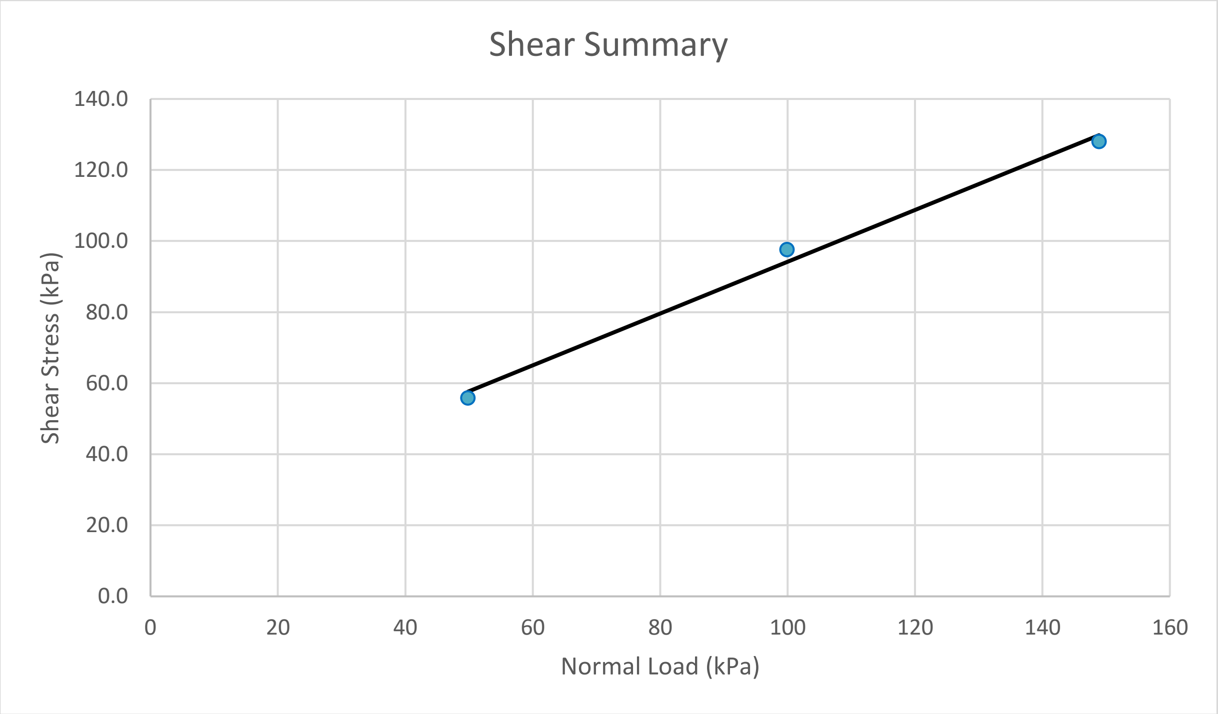
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	18/09/2020
	Jobfile	SWG00088	Sample	E TP57_0.5-1.9m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	36.1
Cohesion (c)	(kPa)	21.30





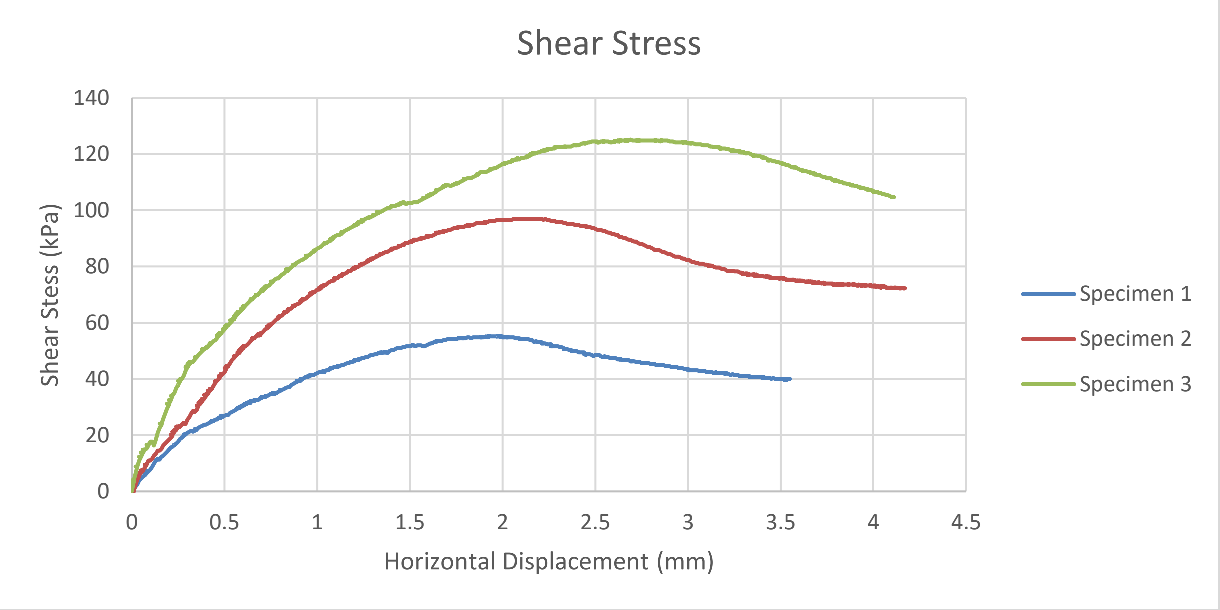
Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
Site Reference		Test Date	18/09/2020
Jobfile	SWG00088	Sample	E TP57_0.5-1.9m
Client	Zutari	Borehole	Clanwilliam Bridging Study
Operator:FC	Checked: FC	Approved: FC	

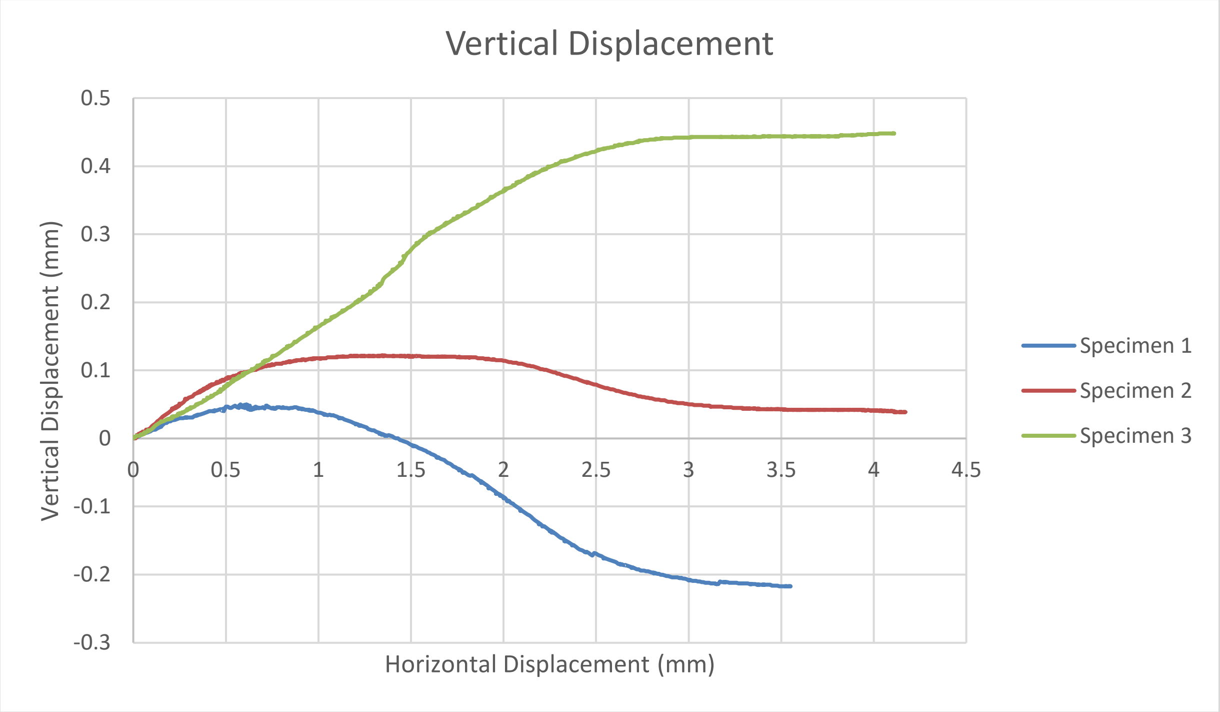
STEYN-WILSON GEOTECHNICAL

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	36.1
Cohesion (c)	(kPa)	21.30





STEYN-WILSON GEOTECHNICAL	Test Method BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference	Test Date	18/09/2020
	Jobfile SWG00088	Sample	E TP57_0.5-1.9m
	Client Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC

Appendix F
Electrical Resistivity Tomography Report and Detailed Results

Electric Resistivity Tomography Survey.

Bridging Study Clanwilliam Dam Project 113834
Western Cape

January 2021

Report by M de Klerk

Prepared for:

Zutari PTY (Ltd)
Riverwalk Office Park, 41 Matroosberg Road, Newlands, Pretoria
South Africa

Cape Geophysics
P.O. Box 1240
Stanford
7210
South Africa

Contact person.

Martin de Klerk
martindeklerk23@gmail.com
Mobile: 0823250747

Mr. G Davis of Zutari PTY(Ltd) Newlands Pretoria, requested Cape Geophysics, Stanford to conduct eight ERT traverses at selected positions for the post feasibility bridging study, raised Clanwilliam dam project, (Figure-1).

Google Earth Locality Map

Figure-1

1. Terms of Reference

Conduct one ERT-2D traverse at the Olifants crossing, four traverses at the Doring river crossing, one traverse at the Doring river extension syphon and two traverses at the Ebenhaeser site.

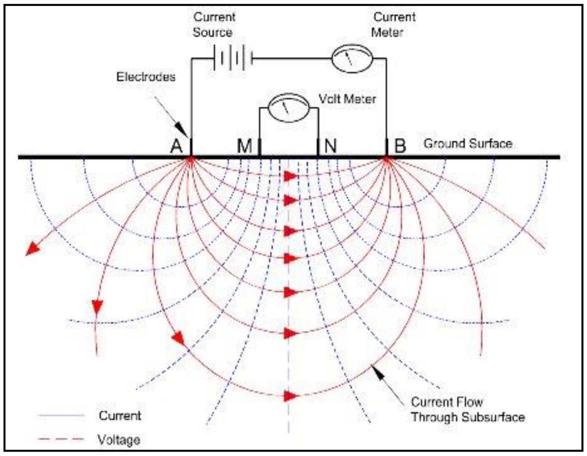
Conduct the ERT surveys with a 4m electrode spacing to obtain an investigation depth of approximately 24m, using the Wenner measuring protocol.

The paragraphs below summarize the basic principles, field survey method and data reduction of the multi-electrode resistivity imaging technique used. The method is also referred to as ERT (Electrical Resistivity Tomography).

A Google (.kmz) file accompanies this report and show the traverse coordinates and ERT models on terrain.

2. Resistivity method

DC resistivity techniques, sometimes referred to as electrical resistivity, 2D(3D) resistivity imaging or electric resistivity tomography (ERT) are used to measure earth resistivity by driving a direct current (DC) signal into the ground and measuring the resultant potentials (voltages) created in the earth. The electrical properties of the sub-surface are derived from this data.



The electrical resistivity varies between different geological materials, depends mainly on variations in water content and dissolved ions in the groundwater. Resistivity investigations thus are used to identify zones with different electrical properties, which can then be referred to different geological strata. Resistivity is also called specific resistance, which is the inverse of conductivity or specific conductance. The most common mineral-forming soils and rocks have very high resistivity in a dry condition; therefore, the resistivity of soils and rocks is normally a function of the amount and quality of water in pore spaces and fractures, as well as the degree of tropical weathering of the formation. Consequently, the variation may be more limited to a confined geological area and variations in resistivity, within a certain soil or rock type, will reflect variations in physical properties. For example, the lowest resistivities encountered for sandstone and limestone imply that the pore spaces in the rock are saturated with water, whereas the highest values represent strongly consolidated sedimentary rock or dry rock above the groundwater surface. Sand, gravel and sedimentary rock may also have very low resistivities, provided that the pore spaces are saturated with saline water.

Fresh crystalline rock is highly resistive, despite the fact that it may contain certain conductive ore minerals; however, weathering commonly produces highly conductive clay-rich saprolite. Variation in characteristics within one geological material type necessitates calibration of resistivity data against geological documentation, from, for example, surface mapping, test pit exposures or drilling. However, this applies to all geophysical methods**.**

The degree of saturation, of course, will affect the resistivity; the resistivity above the groundwater level will be higher than that below this level, i.e. if the material is similar. Consequently, this method can be used to determine the depth to the water table, where a distinct water table exists. However, if the content of fine-grained material is significant, the water content above the groundwater surface, held by hygroscopic and capillary forces, may be large enough to dominate the electrical behaviour of the material. The resistivity of the pore water is determined by concentrations of ions in solution, the type of ions and temperature. The presence of clay minerals strongly affects the resistivity of sediments and weathered rock. The clay minerals may be regarded as electrically conductive particles, which can absorb and release ions and water molecules on its surface through an ion exchange process.

Note.
It is impossible to determine hydrologeogical parameters, such as porosity and transmissivities of a formation through geophysical results. Lower electric resistivities in a homogeneous formation are normally associated with higher porosities and transmissivities. Very low resistivities on the other hand, are associated with clayey and, consequently, low transmissive- or saline-saturated formations.

2.1. Field survey method.

An Abem SAS 1000 Terrameter and ES 10-64 switching unit were used for data acquisition during January 2021. Electrical resistivity measurements were conducted with the Wenner measuring protocol and a 4m electrode spacing. This measuring protocol and electrode spacing yield a maximum investigation depth of approximately 24 meters.

Measurement of the resistivity of the ground is carried out by transmitting a controlled current (I) between two electrodes inserted in the ground, while measuring the potential (V) between two other electrodes. Direct current (DC) or a very low frequency alternating current is used; the method is often called DC-resistivity. The resistance (R) is calculated using Ohm's law.

Traverse coordinates were obtained with a handheld GPS. Elevations along the traverses were obtained from Google Earth.

2.2. Data Reduction.

The RES2Dinv (GEOTOMO) version 3.52-inversion program was used to invert the measured apparent resistivities to obtain the true ground resistivity values below the survey line.

The inversion routine used by the program is based on the smoothness-constrained least-squares method (de Groot-Hedlin and Constable 1990, Sasaki 1992). One advantage of the method is that the damping factor and flatness filters can be adjusted to suit different types of data. The 2-D model used by this program divides the subsurface into a number of rectangular blocks that will produce an apparent resistivity pseudo section that agrees with the actual measurements. A forward modelling subroutine is used to calculate the apparent resistivity values, and a non-linear least-squares optimisation technique is used for the inversion routine. The optimisation method basically tries to reduce the difference between the calculated and measured apparent resistivity values by adjusting the resistivities of the model blocks**.** A measure of this difference is given by the root-mean-squared (RMS) error. However, the model with the lowest RMS error can sometimes show large and unrealistic variations in the model resistivity values and might not always be the "best" model from a geological perspective. In general, the most prudent approach is to choose the model at the iteration after the RMS error does not change significantly**.**

It is important to note that the inversion process that translates raw resistivity data into a resistivity cross section is non-unique. The inversion program chooses the smoothest, least heterogeneous, solution. This solves the mathematical problem of non-uniqueness but produces a slightly blurred image of the actual geology. Abrupt transitions between layers become gradational transitions in the resistivity section. Second, the data are collected along a line and inverted assuming two-dimensional geologic structure. This assumption is reasonable for a layered earth or for dipping layers if the data are collected perpendicular to strike.

A detailed description of the different variations of the smoothness-constrained least-squares method can be found in the free tutorial notes by Loke (2001), www.geoelectrical.com.

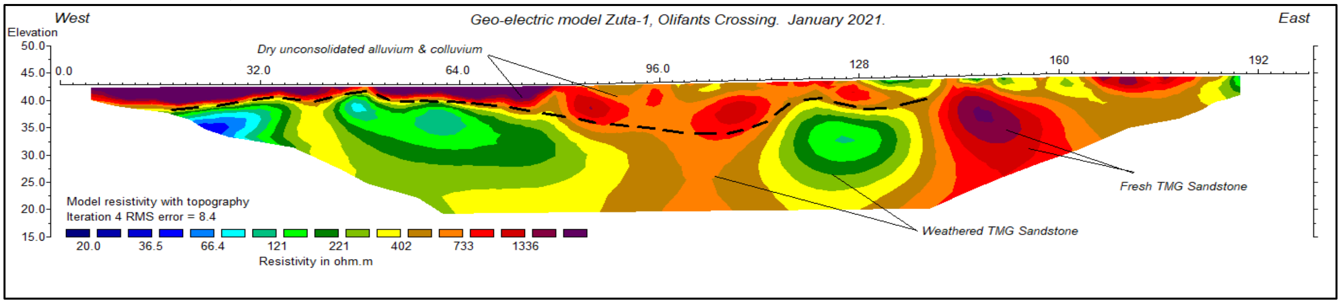
3. ERT Results

3.1. Olifants Crossing

Google Earth image showing ERT traverse position.

Figure-3

ERT Model, Traverse-1.

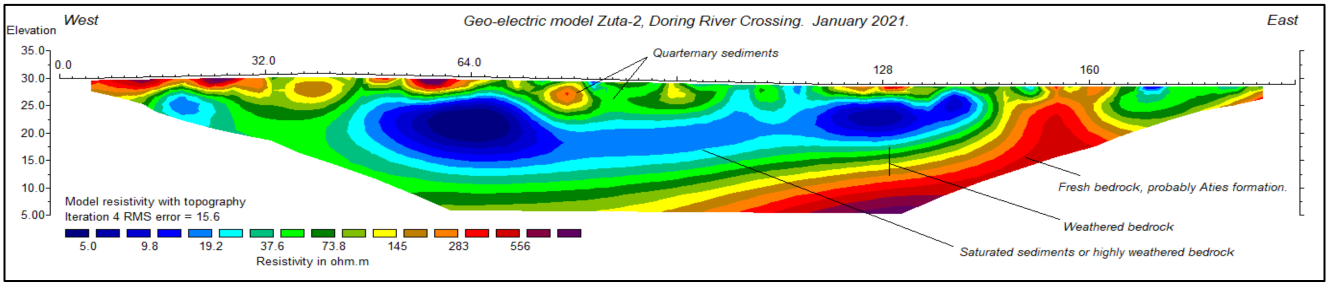


3.2. Doring River Crossing

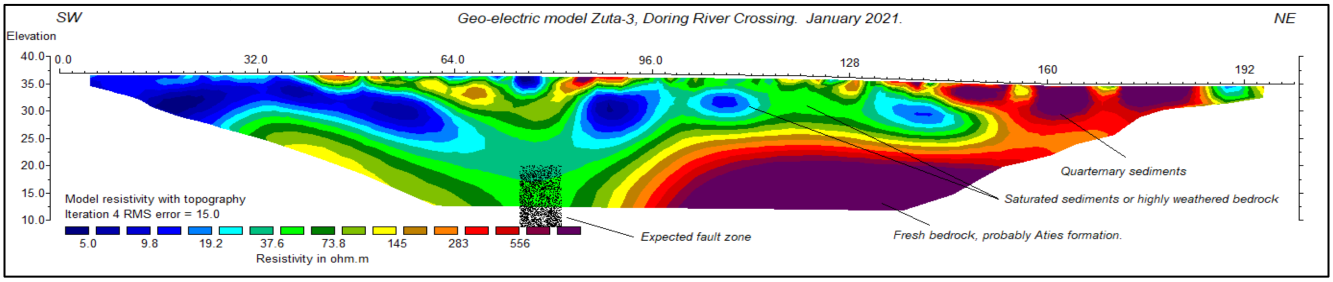
Google Earth image showing ERT traverse positions.

Figure-4

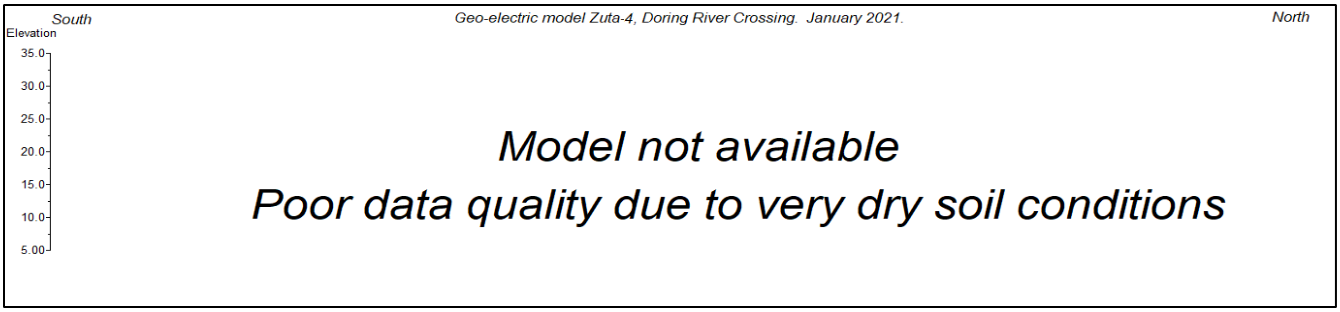
ERT Model, Traverse-2.



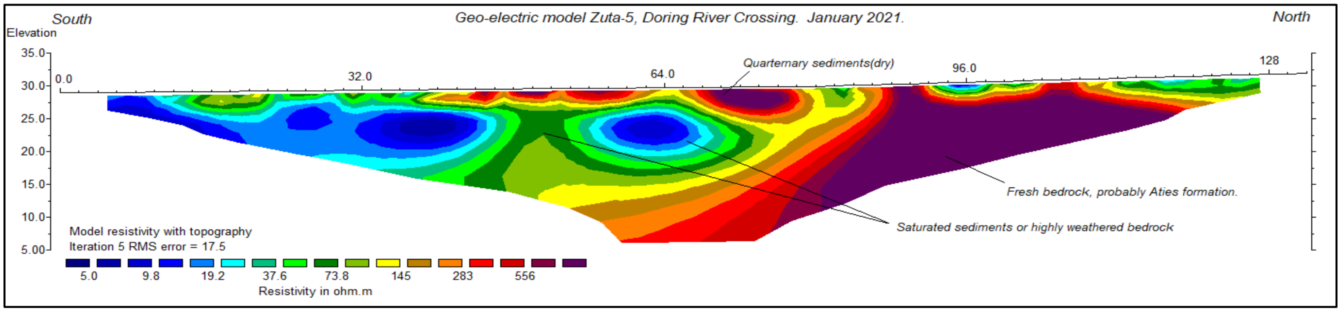
ERT Model, Traverse-3.



ERT Model, Traverse-4.



ERT Model, Traverse-5.

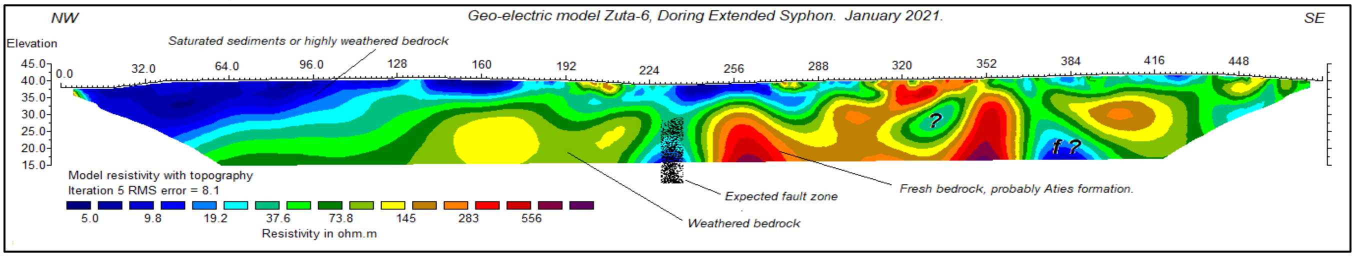


3.3. Doring Extended Syphon

Google Earth image showing ERT traverse position.

Figure-5

ERT Model, Traverse-6.

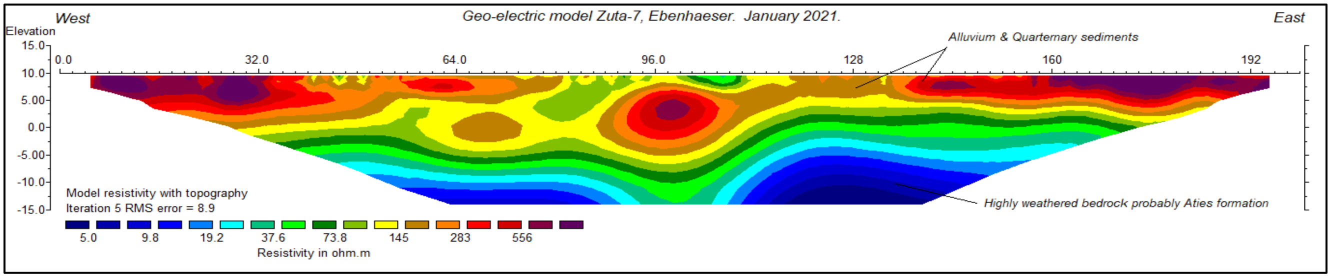


3.4. Ebenhaeser

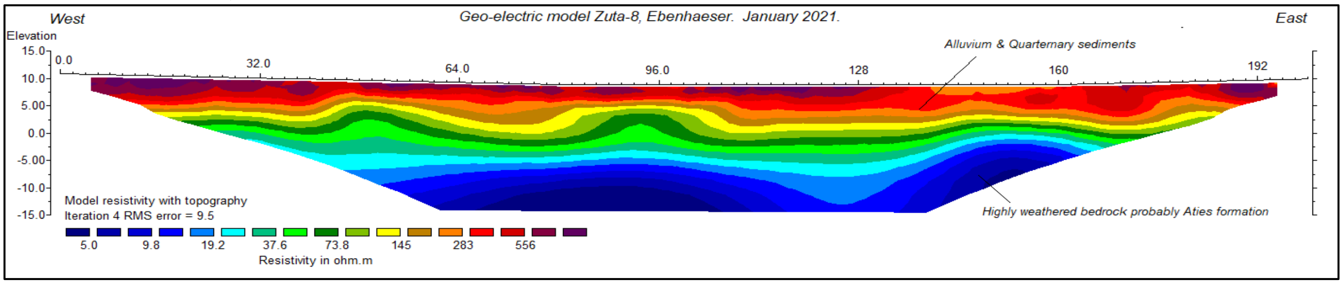
Google Earth image showing ERT traverse positions.

Figure-6

ERT Model, Traverse-7.



ERT Model, Traverse-8.



4. References

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Loke, M.H., 2004. Tutorial: Rapid 2D Resistivity & IP Inversion, Geotomo software, Malaysia.

Loke, M.H., Baker, R.D Geophysical Prospecting Volume 44, Issue 1, Pages131 - 152
1996 European Association of Geoscientists & Engineers

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M de Klerk (Pr. Sci.Nat)
(Geophysicist)
January 2021

Appendix G
Rotary Core Borehole Logs and Photographs

ABREVIATIONS
N/A not applicable
N/M not measureable
IT invalid test
NT no test

JOINT INFILL
Cl Clay
Slt Silt
Snd Sand
St Stained
Cn Clean

JOINT SPACING
VCJ very close spacing
CJ close spacing
MJ medium spacing
WJ wide spacing
VWJ very wide spacing

JOINT ROUGHNESS
S smooth
SR slightly rough
R rough

WEATHERING SHADING
BROWN soil
100% completely weathered
75% highly weathered
50% moderately weathered
25% slightly weathered
0% unweathered

ZUTARI
IMPACT. ENGINEERED.

Clanwilliam Bridging Study
Ebenhaeser
113834
Department of Water and Sanitation

HOLE No: EB BH01
Sheet 1 of 1

Scale 1:60

Reduced Level	Material Recovery %	Core Recovery %	RQD (%)	SPT Test	Joint Inclin. (deg)	Joint Spacing	Joint Rough-ness	Joint Infill	Weathering	Depth	Description
10.00 9.85	100	0	0		-	N/A	N/A	N/A	■	0.00 0.15	Dry, light yellow brown, silty to fine sand, ALLUVIUM / AEOLIAN. Roots and organic matter in layer.
	71	0	0		-	N/A	N/A	N/A	■		Moist to wet, brown to dark brown, silty to clayey sand, ALLUVIUM.
	80	0	0						■		
	66	0	0						■		
8.20	444	0	0	7					■	1.80	
	40	0	0		-	N/A	N/A	N/A	■		Moist, off-white to light brown, silty to coarse sand, ALLUVIUM.
	69	0	0						■		
	64	0	0	7					■		
	51	0	0						■		
	45	0	0	8					■		
	40	0	0						■		
	47	0	0						■		
	87	0	0	29					■		
	38	0	0						■		
	34	0	0						■		
2.25	31	0	0	11					■	7.75	

Scale 1:60

NOTES:

1. End of hole at 7.75m.
2. Some turns wash-bored.

Contractor: BS Moloi Drilling	**Logged by: GD/KM**	**Elevation: 10**
Machine: YWE	**Logged date: 2021/03/02**	**North: -3500304.52**
Drilled by: J.Katjedi	**Drilled date: 2021/03/02 -**	**East: -56200.6**

ABREVIATIONS
N/A not applicable
N/M not measureable
IT invalid test
NT no test

JOINT INFILL
Cl Clay
Slt Silt
Snd Sand
St Stained
Cn Clean

JOINT SPACING
VCJ very close spacing
CJ close spacing
MJ medium spacing
WJ wide spacing
VWJ very wide spacing

JOINT ROUGHNESS
S smooth
SR slightly rough
R rough

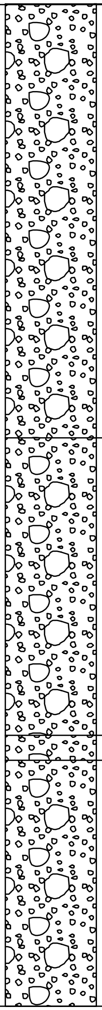
WEATHERING SHADING
BROWN soil
100% completely weathered
75% highly weathered
50% moderately weathered
25% slightly weathered
0% unweathered

ZUTARI
IMPACT. ENGINEERED.

Clanwilliam Bridging Study
Ebenhaeser
113834
Department of Water and Sanitation

HOLE No: EB BH02
Sheet 1 of 1

Reduced Level	Material Recovery %	Core Recovery %	RQD (%)	SPT Test	Joint Inclin. (deg)	Joint Spacing	Joint Rough-ness	Joint Infill	Weathering	Scale 1:60	Depth	Description
9.00	98	0	0	14	-	N/A	N/A	N/A			0.00	Moist, brown, silty sand, ALLUVIUM.
	55	0	0							1		
	70	0	0									
	49	0	0									
	91	0	0	14						2		
	96	0	0									
5.56	47	0	0							3	3.44	
	89	0	0	13	-	N/A	N/A	N/A		4		Moist, brown to dark brown, clayey silty sand, ALLUVIUM.
	89	0	0									
3.20	92	0	0	18						5	5.80	
3.00					-	N/A	N/A	N/A			6.00	Very moist, light brown, coarse sand, ALLUVIUM.
	67	0	0		-	N/A	N/A	N/A		6		Moist, brown to light brown, slightly clayey silty sand, ALLUVIUM.
	44	0	0	18								
	36	0	0							7		
1.05	69	0	0								7.95	
										8		



NOTES:

1. End of hole at 7.95m.

Contractor: BS Moloi Drilling
Machine: YWE
Drilled by: J.Katjedi

Logged by: GD/KM
Logged date: 2021/03/02
Drilled date: 2021/03/02 -

Elevation: 9
North: -3500336.28
East: -56205.97

ZUTARI
IMPACT. ENGINEERED.

PROJECT NAME Bridging Study, Clanwilliam Dam

CONTRACTOR BS Moloi Drilling
DATE PROFILED 01 Mar 2021
DATE DRILLED 23 Feb 2021
BH No. BH E01
SITE Olifants River Crossing
BOX No. 1/1
SCHEME Ebenhaeser
DEPTH (m) FROM 0,00 **to** 7,75

ZUTARI
IMPACT. ENGINEERED.

PROJECT NAME Bridging Study, Clanwilliam Dam

CONTRACTOR BS Moloi Drilling
DATE PROFILED 02 Mar 2021
DATE DRILLED 25 Feb 2021
BH No. BH E02
SITE Olifants River Crossing
BOX No. 1/1
SCHEME Ebenhaeser
DEPTH (m) FROM 0,00 **to** 7,95

Appendix H
SPT Results contained in Drillers Daily Logs

BS MOLOI DRILLING

POSBUS 933, PYRAMID
PRETORIA, GAUTENG
0120

PLOT 269, KAMEELDORING STRAAT
GROOTVLEI, PRETORIA
GAUTENG

2018/453316/07

DAILY DRILLING JOURNAL

				Drilling and Casing			
Client:	DWS	**Drilling Rig:**	YWE	**Type**	***From***	***To***	***Total***
Project:	Clanwilliam Bridging Study	**Driller:**	Johannes Katjedi	**DIG**			
Contract No:		**Supervisor:**	R. Weppelmann	**NXC**	0.00	1.50	1.50
Site:	Olifants Crossing (Ebenhaeser)	**Date:**	23 February 2021	**NWD4**	1.50	7.75	6.25
Borehole No:	BH E01	**Set Up:**	Drive On	**TNW**			
Water Levels:	2.30m	**S.P.T. No:**	5	**GROUT**			
Drilling Angle:	Vertical	**Block :**	1	**Piezo**			
Direction:		**Standpipe:**	none				
Shelby's	0	**Core Boxes:**	1	**Casing**	0.00	7.30	7.30

	Depth Drilled		**Runs**	**Drilling**	**Core Recovery**			**cat W/T**	**Strata Depth**		**Test Depth**	**S.P.T.Nr. Of Blows**
Date	**From**	**To**	**Adv.**	**Type**	**Meters**	**%**	**Strata Description**		**From**	**To**	**Meter**	**per 7.5 cm**
23-Feb-21	0.00	0.15	0.15	NXC	0.15	100						
	0.15	0.50	0.35	“	0.24	69	Loose brown river sand.	A	0.00	7.75		
	0.50	1.00	0.50	“	0.40	80						
	1.00	1.50	0.50	“	0.31	62						
	1.50	1.95	0.45	SPT	0.33	73					**1.50**	1/2/1/2/2/2
	1.95	2.42	0.47	“	0.18	38						
	2.42	2.81	0.39	“	wash							
	2.81	3.26	0.45	SPT	0.33	73					**2.81**	1/1/1/2/2/2
	3.26	4.31	1.05	“	0.52	50						
	4.31	4.76	0.45	SPT	0.28	62					**4.31**	2/1/2/2/2/2/
	4.76	5.28	0.52	“	wash							
	5.28	5.83	0.55	“	0.29	53						
	5.83	6.28	0.45	SPT	0.45	100					**5.83**	2/4/6/6/8/9
	6.28	6.80	0.52	“	wash							
	6.80	7.30	0.50	“	wash							
Wl=3.30m	7.30	7.75	0.45	SPT	0.21	47					**7.30**	2/2/4/3/2/2
					3.69		Core Recovery					
01-Feb-26												
Wl-2.30m												
							7.75m End of BH					

Remarks: New GPS Location : S 31 37' 35.5”, E 018 24' 25.3”

BS MOLOI DRILLING

POSBUS 933, PYRAMID
PRETORIA, GAUTENG
0120

PLOT 269, KAMEELDORING STRAAT
GROOTVLEI, PRETORIA
GAUTENG

2018/453316/07

DAILY DRILLING JOURNAL

				Drilling and Casing			
Client:	DWS	**Drilling Rig:**	YWE				
Project:	Clanwilliam Bridging Study	**Driller:**	Johannes Katjedi	**Type**	***From***	***To***	***Total***
Contract No:		**Supervisor:**	R. Weppelmann	**DIG**			
Site:	Olifants Crossing (Ebenhaeser)	**Date:**	25 February 2021	**NXC**	0.00	1.50	1.50
Borehole No:	BH E02	**Set Up:**	Drive On	**NWD4**	1.50	7.95	6.45
Water Levels:	6.3m	**S.P.T. No:**	5	**TNW**			
Drilling Angle:	Vertical	**Block :**	1	**GROUT**			
Direction:		**Standpipe:**	none	**Piezo**			
Shelby's	0	**Core Boxes:**	1	**Casing**	0.00	7.52	7.52

Date	**Depth Drilled**		**Runs**	**Drilling**	**Core Recovery**		**Strata Description**	**cat W/T**	**Strata Depth**		**Test Depth**	**S.P.T.Nr. Of Blows**
	From	**To**	**Adv.**	**Type**	**Meters**	**%**			**From**	**To**	**Meter**	**per 7.5 cm**
25-Feb-21	0.00	0.50	0.50	NXC	0.49	98						
	0.50	1.10	0.60	“	0.32	53	Brown sandy soil, slightly clayey,		0.00			
	1.10	1.50	0.40	“	0.26	65	saturated and sandy in depth			7.95		
	1.50	1.95	0.45	SPT	0.27	60					**1.50**	2/2/3/3/4/4
	1.95	2.51	0.56	NWD4	0.53	95						
	2.51	2.99	0.48	“	0.45	94						
	2.99	3.44	0.45	SPT	0.28	62					**2.99**	2/2/3/3/4/4
	3.44	4.50	1.06	NWD4	0.94	89						
26-Feb-21	4.50	4.95	0.45	SPT	0.40	89					**4.50**	3/3/3/3/3/4
WL=0.68m	4.95	6.00	1.05	NWD4	0.98	93						
	6.00	6.45	0.45	SPT	0.33	73					**6.00**	2/2/3/4/5/6
	6.45	7.00	0.55	NWD4	0.24	44						
	7.00	7.50	0.50	“	0.18	36						
	7.50	7.95	0.45	SPT	0.36	80					**7.50**	3/3/3/5/5/5
WL= 6.3m					6.03		Core Recovery					
							7.95m End of BH					

Remarks: New GPS Location : S 31 37' 36.6”, E 018 24' 25.2”

Appendix I
Probabilistic Seismic Hazard Analysis for the Clanwilliam Dam (excerpt from Aurecon Report 106310-G5-01 Clanwilliam Dam: Second Engineering Geological Report for Design of Dam Raising)

PROBABILISTIC SEISMIC HAZARD ANALYSIS FOR THE CLANWILLIAM DAM, SOUTH AFRICA

Submitted to

AURECON South Africa (Pty) Ltd *(Reg. No: 1997/003711/07*)
(“AURECON”)

Aurecon Centre, 1040 Burnett Street, Hatfield, Tshwane,
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Prepared by

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Report No: 2011-002 (Rev 1.01)

Olifants River, Clanwilliam Dam

Table of Content

Appendices

3. The Cornell-McGuire PSHA Methodology
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Appendix C: Seismic Sources and their Recurrence Parameters

Appendix D: Applied Ground Motion Perdition Equations

Appendix E: Results of PSHA. Tabulated values of mean activity rate, return periods and probability of exceedance in 1, 50, 100 and 1 000 years for specified values of PGA

Appendix F: Attenuation of vertical peak acceleration (by N. A. Abrahamson and J.J. Litehiser)

Compiled by:

A. Kijko

……………………………………………………………………………………

Prof. A. Kijko 3 March 2011 (Rev. 1.00); 9 April 2011 (Rev. 1.01)
NHAC

1. Executive Summary

A Probabilistic Seismic Hazard Analysis (PSHA) has been performed for the considered Clanwilliam Dam site, South Africa. All earthquakes located within a radius of 320 km from the dam site were used in the assessment. The PSHA was performed using the Cornell-McGuire procedure which can be broken down into two phases: 1) spatial delineation of seismogenic sources within 320 km from the site and 2) integration of all possible earthquake scenarios from each source to obtain probabilities of exceedance of specified ground motion parameters.

All calculations are repeated two times, each for different ground motion prediction equation (GMPE). The models of ground motion prediction are:

- Atkinson and Boore, 2006 [GMPE-1]
- Spudich *et al.*, 1999 [GMPE-2]

The first GMPE (Atkinson and Boore, 2006) was developed for the central and eastern United States which is situated in a type of tectonic environment known as an intraplate region, or equivalently, stable continental area. Because of the limited number of strong-motion records in the stable continental areas, the attenuation relation (horizontal component) has been developed mainly by help of stochastic modelling.

The second GMPE (Spudich *et al.*, 1999) is appropriate for predicting earthquake generated horizontal component of ground motions in extensional tectonic regimes. The area which is located between the Sierra Nevada Mountains in eastern California and the Wasatch Mountains in central Utah, are an example of shallow extensional tectonic environment. Some parts of Western Europe, parts of Italy and Greece, the East African Rift System are other examples of extensional environment. In general, the relationships predict lower ground motions than any other applied ground motion prediction equation.

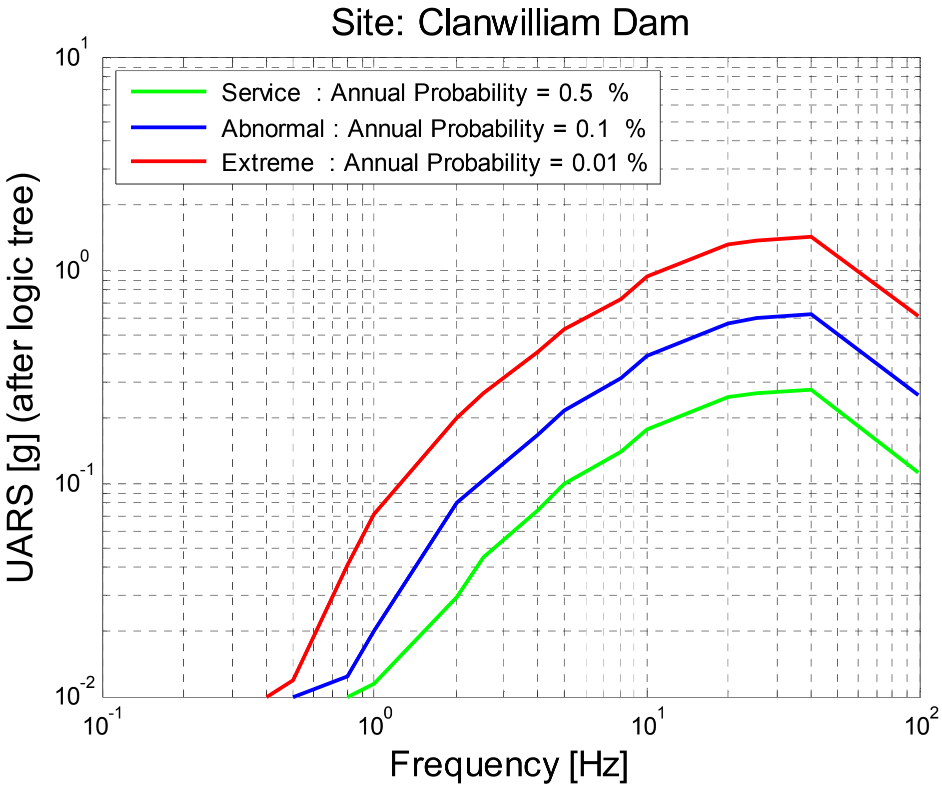
The PSHA was performed using conventional, Cornell-McGuire procedure (Cornell, 1968; McGuire, 1976; 1978), where the integration across the uncertainty in the PGA prediction equation is an integral part of the methodology.

In accordance to the guideline ICOLD (1989), and current seismic regulations as e.g. Eurocode 8 (2004) and ASCE (2005), three seismic designed levels were considered: Operating Basis Earthquake (OBE), Maximum Design Earthquake (MDE) and Maximum Credible Earthquake (MCE).

Given the existence of four faults in vicinity of the dam site, an investigation of the effect of seismic activity of the faults on the seismic hazard assessment was performed.

The results of PSHA are given in terms of mean return periods and probabilities of being exceeded, for horizontal component of PGA. The uniform response spectra are also provided.

After application of logic tree formalism to the uniform horizontal ground acceleration spectra, the service, abnormal and extreme curves show a spectral acceleration peak of approximately 0,3 g, 0,6 g and 1,6 g at 40 Hz, respectively.



A simple procedure for conversion of PSHA characteristics from *horizontal* to *vertical* component of PGA and spectra is described in Appendix F.

The lack of the regional ground motion prediction equation and information about seismic potential of four faults identified in vicinity of the dam site are the main sources of uncertainty in this PSHA assessment for the Clanwilliam Dam. The uncertainty can be significantly reduced by implementation of results of additional geological investigation on the site.

2. Definition of Terms, Symbols and Abbreviations

Acceleration	The rate of change of particle velocity per unit time. Commonly expressed as a fraction or percentage of the acceleration due to gravity (g), where $g = 9.81$ m/s^2.
Acceleration Response Spectra (ARS)	Spectral acceleration is the movement experienced by a structure during an earthquake.
Annual Probability of Exceedance	The probability that a given level of seismic hazard (typically some measure of ground motions, e.g., seismic magnitude or intensity), or seismic risk (typically economic loss or casualties)
Area-specific mean seismic activity rate (λ_A)	Mean rate of seismicity for the whole selection area in the vicinity of the site for which the PSHA is performed.
Attenuation	A decrease in seismic-signal amplitude as waves propagate from the seismic source. Attenuation is caused by geometric spreading of seismic-wave energy and by the absorption and scattering of seismic energy in different earth materials.
Attenuation law - ground motion prediction equation (GMPE)	A mathematical expression that relates a ground motion parameter, such as the peak ground acceleration, to the source and propagation path parameters of an earthquake such as the magnitude, source-to-site distance, fault type, etc. Its coefficients are usually derived from statistical analysis of earthquake records. It is a common engineering term known as ground motion prediction equation (GMPE).
b-value (*b)*	A coefficient in the frequency-magnitude relation, $\log N(m) = a - bm$, obtained by Gutenberg and Richter (1941; 1949), where m is the earthquake magnitude and $N(m)$ is the number of earthquakes with magnitude greater than or equal to m. Estimated *b*-values for most seismic sources fall between 0,6 and 1,2.
Capable (active) fault	A mapped fault that is deemed a possible site for a future earthquake with magnitude greater than some specified threshold.
Catalogue (seismic events)	A chronological listing of earthquakes. Early catalogues were purely descriptive, i.e., they gave the date of each earthquake and some description of its effects. Modern catalogues are usually quantitative, i.e., earthquakes are listed as a set of numerical parameters describing origin time, hypocenter location, magnitude, focal mechanism, moment tensor, etc.
Design Earthquake	The postulated earthquake (commonly including a specification of the ground motion at a site) that is used for evaluating the earthquake resistance of a particular structure.
Elastic design spectrum (or spectra)	The specification of the required strength or capacity of the structure plotted as a function of the natural period or frequency of the structure appropriate to earthquake response at the required level. Design spectra are often composed of straight line segments (Newmark and Hall, 1982) and/or simple curves, for example, as in most building codes, but

	they can also be constructed from statistics of response spectra of a suite of ground motions appropriate to the design earthquake(s). To be implemented, the requirements of a design spectrum are associated with allowable levels of stresses, ductilities, displacements or other measures of response.
Earthquake	Ground shaking and radiated seismic energy caused most commonly by sudden slip on a fault, volcanic or magmatic activity, or other sudden stress changes in the Earth.
Epicentre	The epicentre is the point on the earth's surface vertically above the hypocenter (or focus).
Epicentral distance (Δ)	Distance from the site to the epicentre of an earthquake.
Fault	A fracture or fracture zone in the Earth along which the two sides have been displaced relative to one another parallel to the fracture. The accumulated displacement may range from a fraction of a meter to many kilometres. The type of fault is specified according to the direction of this slip. Sudden movement along a fault produces earthquakes. Slow movement produces a seismic creep.
Focal depth (h)	Focal depth is the vertical distance between the hypocentre and epicentre.
Frequency	The number of cycles of a periodic motion (such as the ground shaking up and down or back and forth during an earthquake) per unit time; the reciprocal of period. Hertz (Hz), the unit of frequency, is equal to the number of cycles per second.
Ground motion	The movement of the earth's surface from earthquakes or explosions. Ground motion is produced by waves that are generated by sudden slip on a fault or sudden pressure at the explosive source and travel through the earth and along its surface.
Ground motion parameter	A parameter characterizing ground motion, such as peak acceleration, peak velocity, and peak displacement (peak parameters) or ordinates of response spectra and Fourier spectra (spectral parameters).
Heterogeneity	A medium is heterogeneous when its physical properties change along the space coordinates. A critical parameter affecting seismic phenomena is the scale of heterogeneities as compared with the seismic wavelengths. For a relatively large wavelength, for example, an intrinsically isotropic medium with oriented heterogeneities may behave as a homogeneous anisotropic medium.
Hypocenter	The hypocenter is the point within the earth where an earthquake rupture starts. The epicentre is the point directly above it at the surface of the Earth. Also commonly termed the focus.
Hypocentral distance (r)	Distance from the site to the hypocenter of an earthquake.
Induced earthquake	An earthquake that results from changes in crustal stress and/or strength due to man-made sources (e.g., underground

	mining and filling of a water reservoir), or natural sources (e.g., the fault slip of a major earthquake). As defined less rigorously, “induced” is used interchangeably with “triggered” and applies to any earthquake associated with a stress change, large or small.
Local Magnitude (M_L)	A magnitude scale introduced by Richter (1935) for earthquakes in southern California. M_L was originally defined as the logarithm of the maximum amplitude of seismic waves on a seismogram written by the Wood-Anderson seismograph (Anderson and Wood, 1925) at a distance of 100 km from the epicentre. In practice, measurements are reduced to the standard distance of 100 km by a calibrating function established empirically. Because Wood-Anderson seismographs have been out of use since the 1970s, M_L is now computed with simulated Wood-Anderson records or by some more practical methods.
Magnitude	In seismology, a quantity intended to measure the size of earthquake and is independent of the place of observation. Richter magnitude or local magnitude (M_L) was originally defined in Richter (1935) as the logarithm of the maximum amplitude in micrometers of seismic waves in a seismogram written by a standard Wood-Anderson seismograph at a distance of 100 km from the epicentre. Empirical tables were constructed to reduce measurements to the standard distance of 100 km, and the zero of the scale was fixed arbitrarily to fit the smallest earthquake then recorded. The concept was extended later to construct magnitude scales based on other data, resulting in many types of magnitudes, such as body-wave magnitude (m_b), surface-wave magnitude (M_S), and moment magnitude (M_W). In some cases, magnitudes are estimated from seismic intensity data, tsunami data, or duration of coda waves. The word “magnitude” or the symbol M, without a subscript, is sometimes used when the specific type of magnitude is clear from the context, or is not really important.
Maximum Regional Earthquake Magnitude (m_{max})	Upper limit of magnitude for a given seismogenic zone or entire region. Often also referred to as the maximum credible earthquake (MCE).
Operating Basis Event (OBE)	Event with an average return period in the order of 145 years i.e. 50 % probability of exceedance in 100 years.
Oscillator	In earthquake engineering, an oscillator is an idealized damped mass-spring system used as a model of the response of a structure to earthquake ground motion. A seismograph is also an oscillator of this type
Peak Ground Acceleration (PGA)	The maximum acceleration amplitude measured (or expected) of an earthquake.
Probabilistic Seismic Hazard Analysis (PSHA)	Available information on earthquake sources in a given region is combined with theoretical and empirical relations among earthquake magnitude, distance from the source and local site conditions to evaluate the exceedance probability of a certain ground motion parameter, such as the peak acceleration, at a given site during a prescribed period.
Response spectrum	The response of the structure to a specified acceleration time series of a set of single-degree-of-freedom oscillators with

	chosen levels of viscous damping, plotted as a function of the undamped natural period or undamped natural frequency of the system. The response spectrum is used for the prediction of the earthquake response of buildings or other structures.
Seismic Hazard	Any physical phenomena associated with an earthquake (e.g., ground motion, ground failure, liquefaction, and tsunami) and their effects on land use, man-made structure and socio-economic systems that have the potential to produce a loss. It is also used without regard to a loss to indicate the probable level of ground shaking occurring at a given point within a certain period of time.
Seismic Wave	A general term for waves generated by earthquakes or explosions. There are many types of seismic waves. The principle ones are body waves, surface waves, and coda waves.
Seismic zone	An area of seismicity probably sharing a common cause.
Seismogenic	Capable of generating earthquakes.
Site-specific mean activity rate (λ)	Mean activity rate of the selected ground motion parameter experienced at the site.
Strong ground motion	A ground motion having the potential to cause significant risk to a structure's architectural or structural components, or to its contents. One common practical designation of strong ground motion is a peak ground acceleration (PGA) of 0.05g or larger.
GMPE	Ground motion prediction equation

3. List of Figures and Tables

3.1. List of Figures

3.2. List of Tables

4. Terms of Reference

The Natural Hazard Assessment Consultancy (NHAC) Centurion, was requested by AURECON South Africa (Pty) Ltd *(Reg. No: 1997/003711/07*), Aurecon Centre, 1040 Burnett Street, Hatfield, Tshwane, South Africa, represented by Dr Teb Vorster as *Project Director* (SUB-CONTRACT AGREEMENT of 14 January 2011) to provide desk study of a probabilistic seismic hazard analysis (PSHA) for the site of the Clanwilliam Dam, South Africa, having approximate coordinates latitude 32^{0}10’59.00”S and longitude 18^{0}52’29.90” E.

In general, the hazardous effects of earthquakes can be divided into three categories:

1. Those resulting directly from a certain level of ground shaking
2. Those at the site resulting from surface faulting or deformations
3. Those triggered or activated by a certain level of ground shaking such as the generation of a tsunami or landslide.

This study covers Category 1 only and in case of PSHA is limited to the following investigations:

1. Selection of earthquakes within a radius of 320 km from the site
2. Assessment of earthquake recurrence parameters for the area.
3. Discussion on applicable ground motion prediction equation (GMPE) used in this study.
4. PSHA calculations and provision of seismic hazard curves in terms of peak ground acceleration (PGA) and Uniform (acceleration) response spectra (URS).
5. PGA calculation for the Operating Basis Earthquake (OBE), Maximum Design Earthquake (MDE) and the Maximum Credible Earthquake (MCE). In this report, following the ICOLD guideline (ICOLD, 1989),

the OBE is defined as PGA having return period of 144 years or equivalently having a 50% probability of exceedance in 100 years. The MCE is suggested as PGA having return period of 10,000 years. In addition, following e.g. regulation ER No. 1110-2-1806, (1995), Eurocode 8 (2004), or ASCE 7-05 (2005), the MDE is calculated as PGA having return period of 475 years or equivalently having a 10% probability of exceedance in 50 years.

6. The classic, Newmark and Hall (1982) elastic design spectra for 5% damping anchored at the OBE, MDE and MCE values.

The PSHA was performed using conventional, Cornell-McGuire procedure (Cornell, 1968; McGuire, 1976; 1978), where the integration across the uncertainty in the ground motion prediction equation is an integral part of the methodology.

The procedure used in this seismic hazard assessment consists essentially of two steps. The first step is applicable to seismic sources (known also as seismogenic sources or seismic zones) in the vicinity of the site, for which the seismic hazard analysis is required. The procedure requires an estimation of the *seismic source parameters*. The second step is applicable to a specified *site*, and consists of assessing the *site-specific parameters*, which describe the amplitude distribution of ground motion parameter PGA.

The PGA is the maximum acceleration of the ground shaking during an earthquake. Spectral acceleration is the movement experienced by a *structure* during an earthquake. The acceleration is expressed in units of gravity, *g*, which is equal to 9.81 m/s^2.

The results are given in terms of mean return periods and probabilities of being exceeded for specified values of *horizontal* component of PGA. Simple procedure of conversion of above results from *horizontal* to *vertical* component of PGA is described in paper by Abrahamson and Litehiser, Appendix F.

Lists of all seismic events used in the study are given in Appendix A. The procedure for PSHA as applied in this work is described in Appendix B. Appendix C lists seismic hazard occurrence parameters for identified fault in vicinity of the dam and for background seismicity. Appendix D provides information on the applied GMPE. Appendix E shows the results of the PSHA calculations for the site of the dam. It contains details of the computations, input data and respective hazard parameters. Appendix F provides paper by N. A. Abrahamson and J.J. Litehiser on attenuation of vertical peak acceleration.

All results of calculations are based on the assumption that the dam structure is founded on hard rock. It such assumption is not correct, results of calculations must be corrected for ground conditions.

5. Introduction

The Natural Hazard Assessment Consultancy (NHAC) Centurion, was requested by AURECON South Africa (Pty) Ltd *(Reg. No: 1997/003711/07*), Aurecon Centre, 1040 Burnett Street, Hatfield, Tshwane, South Africa, represented by Dr Teb Vorster as *Project Director* (SUB-CONTRACT AGREEMENT of 14 January 2011) to provide desk study of a probabilistic seismic hazard analysis (PSHA) for the site of the Clanwilliam Dam, South Africa, having approximate coordinates latitude $32^0$10'59.00"S and longitude $18^0$52'29.90" E.

The objective of a PSHA is to obtain the probabilities of the occurrence of seismic events of a specified size in a given time interval. The methodology used in most PSHA was first defined by Cornell (1968). There are four basic steps in a PSHA:

- Step 1 is the definition of seismotectonic sources. Sources may range from small faults to large seismotectonic provinces.
- Step 2 is the definition of earthquake parameters for each source, where each source is defined by an earthquake probability distribution or earthquake recurrence relationship. A recurrence relationship indicates the chance of an earthquake of a given size occurring anywhere inside the source during a specified period. An upper bound for the earthquakes for each source is chosen, which represents the source characteristic, maximum possible earthquake magnitude.
- Step 3 is the estimation of the earthquake effects, using several GMPE, each relating a ground motion parameter, such as PGA with distance and earthquake magnitude.
- Step 4 is the determination of the hazard at the site. The effects of all earthquakes of different sizes occurring at different locations in different earthquake sources at different probabilities of exceedance are integrated into one hazard curve that shows the probability of exceeding different levels of ground motion (such as PGA) at the site during a specified period of time.

The PSHA was performed using the conventional, Cornell-McGuire procedure (Cornell, 1968; McGuire, 1976; 1978), where the integration across the uncertainty in the ground motion prediction equation is an integral part of the methodology.

6. Regional Geology (by G. Davis, AURECON, South Africa)

The regional geology is illustrated in Figures 6.1 and 6.22. The accompanying geological sections are available from the author. The Skurweberg Formation is Silurian in age, i.e. between 444 Ma and 416 Ma; the latter representing the boundary between the Silurian and Devonian Periods. The depositional environments varied between shallow marine and fluvial. The Skurweberg Formation is characterized by thick-bedded (1000 – 2000 mm), profusely cross-bedded, white weathering, medium to coarse grained sandstone and minor conglomerate and is generally 200 m to 400 m thick.

A large-scale change occurred from general subsidence and sedimentation tode formation and uplift; a process known as inversion, when the Cape Fold Belt was formed. The Cape Fold Belt comprises two limbs; a western fold branch characterised by northwest to north striking folds, and an eastern branch characterised by east-west striking folds. The Clanwilliam Dam is located within this western arm of the Cape Fold Belt where the folds comprise relatively open and upright box-folds. At least four pulses of deformation are recognized starting roughly at about 280 Ma with the final event at approximately 230 Ma.

Deformation within the Cape Fold Belt was associated with large scale faulting. Normal faults are common in the western limb of the Cape Fold Belt, forming the north-west trending swarm visible in Figure 1 and defining horst and graben structures.

The area of interest lies within a major synclinal structure. The regional dip of the strata in the vicinity of Clanwilliam Dam is eastwards at angles between 7° and 15°, although there is some variation. Shallower as well as steeper dips are locally present, with dip directions towards the north and west also being recorded.

The Cape folding and thrusting was also associated with lower greenschist grade metamorphism. Although the effects are more pronounced in the southern limb, recrystallization of the quartz framework grains is typical.

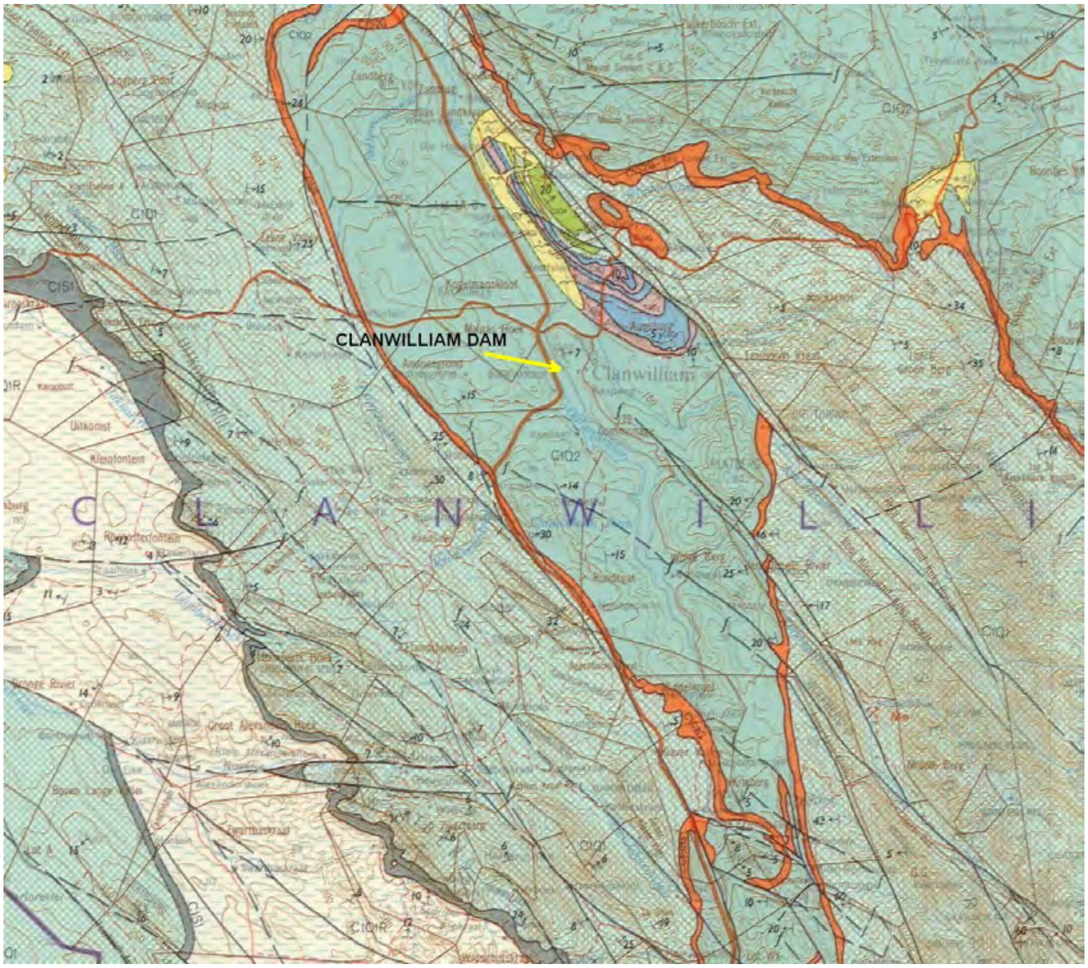


Figure 6.1. Regional geological setting; from the 1:250 000 geological map, Sheet 3218 Clanwilliam (Council for Geoscience, Pretoria).

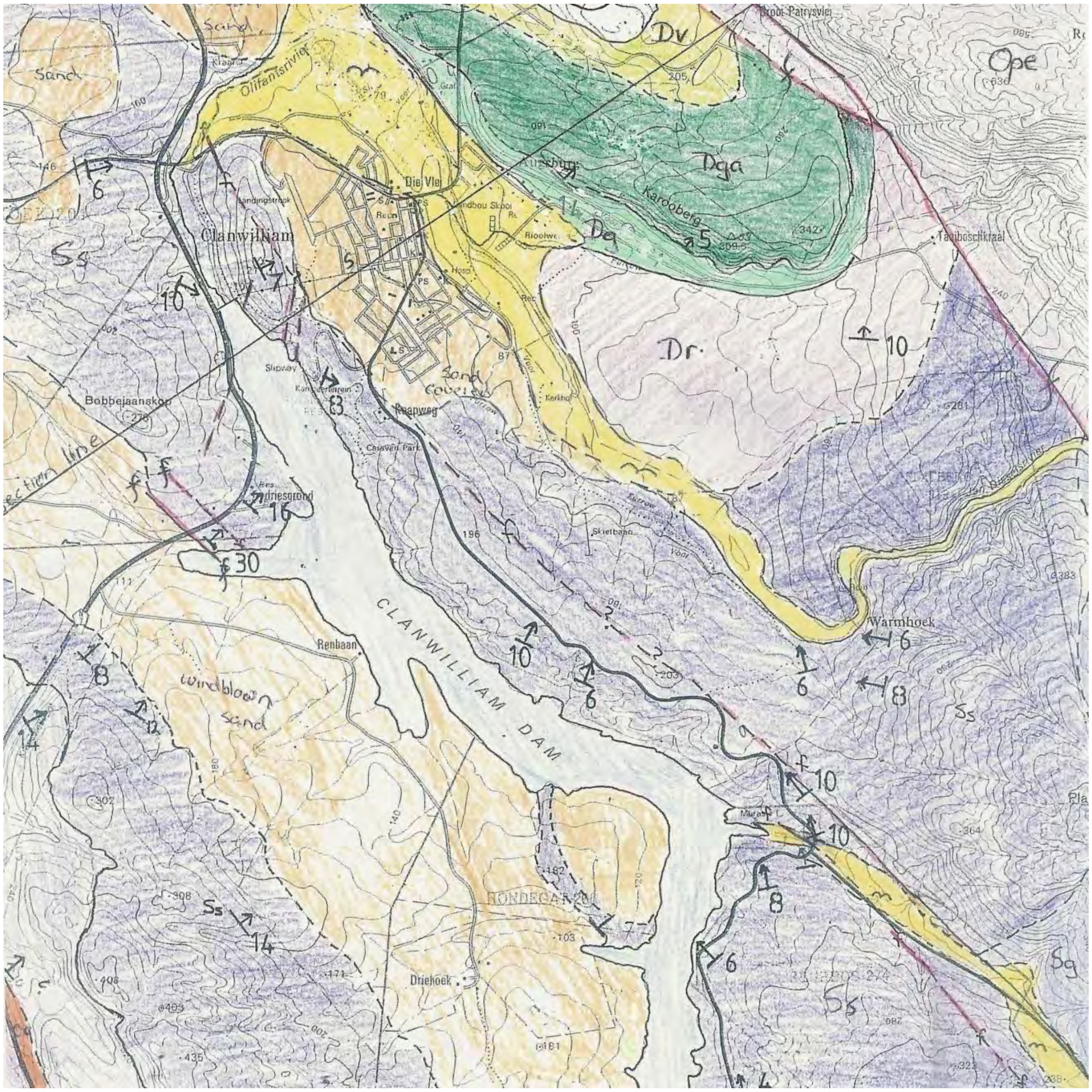


Figure 6.2. Regional geology of the Clanwilliam Dam environs (after 1:50 000 geological field sheet – Council for Geoscience, Pretoria).

The next major tectonic event to occur was the breakup of Gondwana. Five stages in the break-up are recognized, occurring between 180 Ma and 90 Ma. Not all these stages would have a bearing on the strata in the area of the Clanwilliam Dam; some of the more significant events which would have impacted on the Western Cape include the following;

- Development of the Agulhas Falklands Fracture Zone (AFFZ) which is located off the southern coast and has a NE-SW orientation. Strike-slip movement was associated with this zone.
- Further movement along the AFFZ may have been responsible for N-S rifting in the South Atlantic.
- On a regional scale (refer 1:250 000 Geological Map), a number of major faults can be identified within these Table Mountain Group rocks. The general trend of these features is striking in a rough north-west to south-east direction.
- A number of north-east striking lineaments are evident on aerial photographs. It is not clear, however, exactly what these lineaments represent. Brecciated rock present in the road cutting immediately to the north of the dam suggests this lineament might be a fault, but the extent and direction are not clear. A north-northwest to south-southeast strike is most likely.

The locality of the Clanwilliam Dam coincides roughly with the climatic N-value of N = 10 (Weinert, 1980), indicating that disintegration, i.e. physical breakdown of the rock, is the dominant mode of weathering. This implies that the weathering profile is not developed to any significant extent, although some secondary minerals may develop.

7. Seismic Sources and their Parameters

Figure 7.1 shows the distribution of all known seismic events with magnitude M_W=3.0 and stronger, that occurred within a radius of 320 km from the dam site. Only largest events within a radius of 320 km from the dam site were used in the analysis, as only these events can be considered to contribute to the seismic hazard at the dam site. Events at larger distances from the structure will not likely generate PGA's large enough to be of engineering concern. The seismic event catalogue used in this study was compiled from several sources. After critical analysis of each of the data source, the main contribution to applied catalogue come from databases provided by International Seismological Centre in UK. List of seismic events used in the study is given in Appendix A.

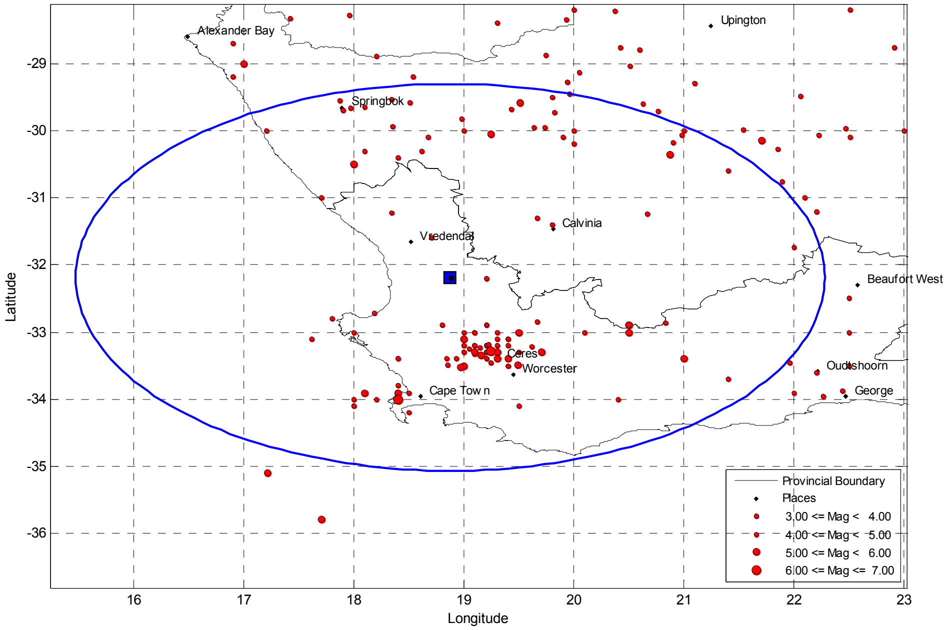


Figure 7.1 Distribution of largest seismic events within 320 km radius of the Clanwilliam Dam site used in the study. The location of dam wall is shown as a blue square.

The close-up view of four faults in vicinity of Clanwilliam Dam (G. Davis, personal communication), is shown in Figure 7.2. The location of dam wall is shown as a blue square.

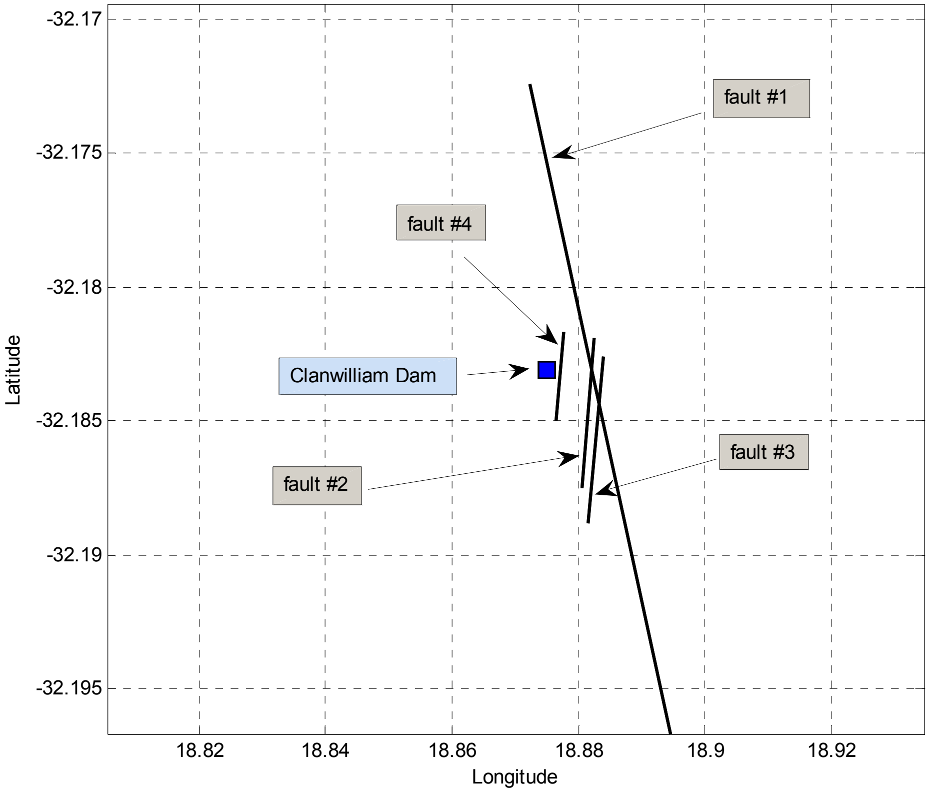


Figure 7.2 Close-up view of four faults in vicinity of Clanwilliam Dam (G. Davis, personal communication). The location of dam wall is shown as a blue square.

It is assumed that magnitudes of earthquakes recorded within specified area are distributed according to the Gutenberg-Richter relation

$$\log n(m) = a - b \cdot m, \tag{7.1}$$

where a is a constant, b refers to the slope of the line, m is the earthquake magnitude and n the cumulative number of earthquakes occurring annually within a magnitude interval $< m, m + \Delta m >$, or the number of earthquakes equal or larger than m. The parameter a is the *measure of the level of seismicity*, whereas the parameter b, which is typically close to 1, describes the *ratio* between number of small and large magnitude events.

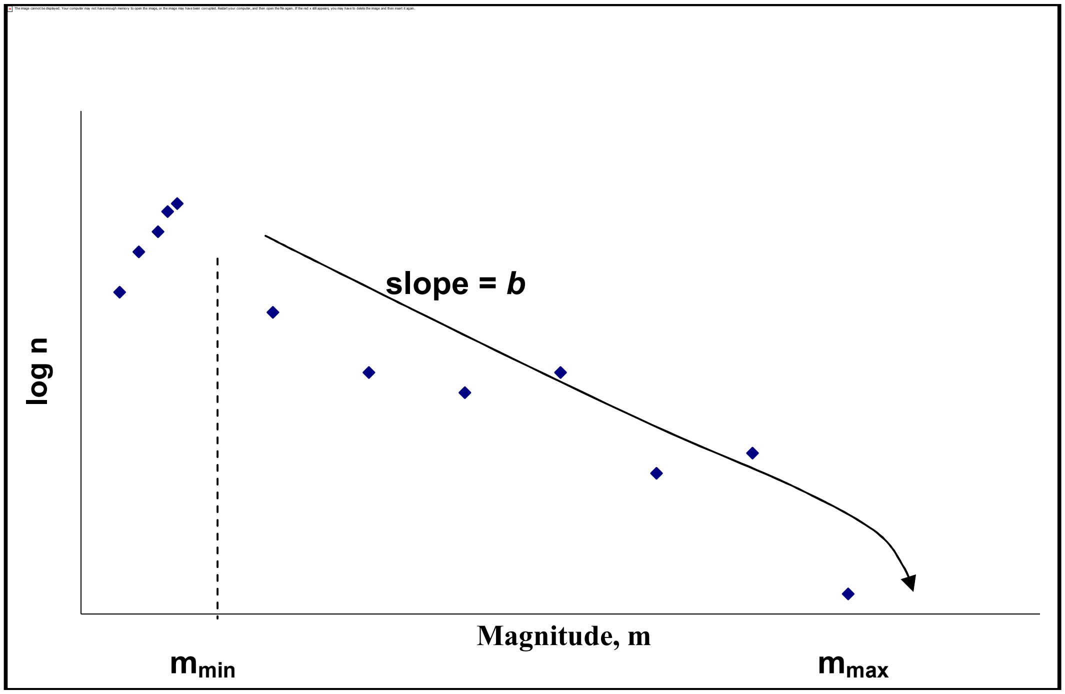


Figure 7.3 Schematic illustration of the doubly truncated frequency-magnitude Gutenberg-Richter relation. The slope of the curve is described by parameter b, known as the b-value of the Gutenberg-Richter. Value $m_{\min}$ is the minimum earthquake magnitude to be considered and $m_{\max}$ is the regional characteristic, maximum possible earthquake magnitude.

Acceptance of the classic frequency-magnitude Gutenberg-Richter relation (7.1) is equivalent to the assumption that the cumulative distribution function (CDF) of earthquake magnitude distribution is of the form

$$F_M(m) = \frac{\exp(-\beta m_{\min}) - \exp(-\beta m)}{\exp(-\beta m_{\min}) - \exp(-\beta m_{\max})}. \tag{7.2}$$

In Fig 7.3 and equation (7.2), $m_{\min}$ is the minimum earthquake magnitude for which the earthquake catalogue is considered complete, $m_{\max}$ is the maximum possible earthquake magnitude, and $\beta = b \ln 10$, where b is the parameter of the Gutenberg-Richter magnitude-frequency relation (6.1).

Following Cornell (1968), each seismic source (area source as well as fault source) is described by three parameters: the mean seismic activity rate λ, Gutenberg-Richter b-value, and $m_{\max}$.

The mean seismic activity rate λ, is defined as the ratio

$$\lambda = \frac{Number\ of\ earthquakes\ with\ m \geq m_{\min}}{Time\ span\ of\ observations} \quad , \tag{7.3}$$

or equivalently as

$$\lambda = \frac{n(m \geq m_{\min})}{t}$$

where n is the number of earthquakes of magnitude $m_{\min}$ and greater that occurred within a specified time interval t.

One can show that parameters a and b, level of completeness m_{min} and the mean activity rate λ, are linked together, and the following equation holds

$$a = \log_{10} \lambda + b \cdot m_{\min} \tag{7.4}$$

The parameters of area sources, λ , b-value and m_{max} were calculated for a grid spanning the area of 320 km radius. For the site, the area of 320 km radius was divided into 50km x 50km seismic sources for which the parameters were selected from the grid.

In this investigation the recurrence parameters: the mean activity rate λ , b-value of Gutenberg-Richter and seismic source characteristic $m_{\max}$ are calculated according to maximum likelihood procedure developed Kijko and Sellevoll (1992) and Kijko (2004). The applied approach accounts for incompleteness and uncertainty in the seismic event catalogues. More details can be found in the description of the applied methodology in Appendix B.

Reports of seismic phenomena in South Africa go back as far as 1620, to the early Dutch settlers. The seismicity is typically that of an intra-plate region. The natural seismic regime of a region of this type is characterised by a low-level activity by world standards, with earthquakes randomly distributed in space and time. The correlation between most of the earthquakes and the surface expression of major geological features is not clear (Fernandez and Guzman, 1979, Brandt *et al.*, 2003).

Seismic events resulting from the deep-mining operations in the gold fields of the Gauteng, Klerksdorp and Welkom, form the majority of the seismic events recorded by the regional network of seismic stations. Usually, the depth of these events varies in the range of 2-3 km below the surface.

The seismic event catalogue used in this study was compiled from several sources. After critical analysis of each of the data source, the main contribution to pre-instrumentally recorded seismicity come from Brandt *et al.* (2003). The instrumentally recorded events are mainly selected from databases provided by the International Seismological Centre in UK.

The database of seismic events for South Africa is incomplete, due to the fact that large parts of the area were very sparsely populated and the detection capabilities of the seismic network are far from uniform.

Following extensive analysis of the earthquake database it was established that the catalogue of the tectonic origin earthquakes can be divided into 8 parts, each with different level of completeness, (Table 7-1).

Table 7-1. Division of the catalogue used in the analysis.

Subcatalogue number	**Level of completeness (M_w)**	**Beginning of the subcatalogue**	**End of subcatalogue**
1	5.9	1806/01/01	1905/12/31
2	5.3	1906/01/01	1909/12/31
3	4.9	1910/01/01	1949/12/31
4	4.6	1950/01/01	1970/12/31
5	4.0	1971/01/01	1980/12/31
6	3.8	1981/01/01	1990/12/31
7	3.5	1991/01/01	2002/12/31
8	3.3	2003/01/01	2006/09/30

The parameters of area sources, λ, b-value and $m_{\max}$ were calculated for a grid spanning the whole country. For the site, the area of 320 km radius was divided into 50km x 50km seismic sources for which the parameters were selected from the grid.

From all faults identified in vicinity of the dam site, four faults have been considered as potential sources of seismicity (G. Davis, personal communication, Figure 7.2). Unfortunately, current geological knowledge of the area does not provide information on potential movement of identified faults during the recent (Quaternary) geological past, especially during last 35,000 years. No relationships between instrumentally recorded seismicity or historic events and faults location could be established. Also, no information on paleo-seismicity of the area was available. Therefore, in this report, the assessment of the maximum possible earthquake magnitude $m_{\max}$, which can be generated by the faults, is based on faults length. Our procedure of $m_{\max}$ estimation for each fault consists from two steps: (1) estimation of the most probable rupture length of the fault, and (2) estimation of the maximum possible fault-characteristic earthquake magnitude $m_{\max}$ based on empirical equations relating surface rupture length with moment magnitude.

In step one, estimation of the most probable rupture length of the fault was performed according to procedure developed by Slemmons and Chung (1982). Slemmons and Chung (1982) has show that in average, fraction of a fault that ruptures, increases linearly with fault length according to formula $\mathrm{PRC}(L) = 15.76 + 0.012 \cdot L$, where $\mathrm{PRC}(L)$ is percent of total fault length that ruptures and L is total fault in km.

In Step 2, we input estimated rupture length into well known Wells and Coppersmith (1994) empirical equation, relating surface rupture length to moment magnitude. So estimated earthquake magnitude is considered as a fault characteristic, maximum earthquake magnitude $m_{\max}$. The other two hazard recurrence parameters (the Gutenberg-Richter b-value and the mean activity rate

λ) for each source fault has been estimated according to procedure developed by Kijko and Sellevoll (1992) and are based on knowledge of seismicity of the area.

It must be noted once again, that seismicity of the studied area cannot be directly correlated with tectonic or known geologic structures (Fernandez and Guzman, 1979). Even in case of localization of a few seismic events in the vicinity of the fault, a significant correlation could not be established due to the poor earthquake location. The earthquake locations in the studied area have a considerable error, order of 100 km for the events located prior 1971 (Saunders *et al.*, 2008).

All characteristics of four considered faults (Figure 7.2), as coordinates of its edges, total fault length, segment length with corresponding maximum earthquake magnitude, the assumed mean seismic activity rate λ, *b*-value of Gutenberg-Richter and shortest distance to the dam site are given in Appendix C.

8. Ground Motion Prediction Equations (GMPE)

Attenuation is the reduction in amplitude or energy of seismic waves caused by the physical characteristics of the transmitting media or system. It usually includes geometric effects such as the decrease in amplitude of a wave with increasing distance from the source.

Attenuation relationships known as ground motion prediction equations (GMPE) for the investigated area established on base of strong motion data are practically non-existent (Minzi *et al*., 1999). Two attempts to establish horizontal component of PGA attenuation for the Eastern and Southern Africa are published: one by Jonathan (1996) and one by Twesigomwe (1997). Jonathan's GMPE is based on the random vibration theory and scaled by some seismic records recorded by local seismic stations. Twesigomwe's equation is a modification of GMPE by Krinitzky *et al*. (1988). Comparison of the two regional GMPE with the e.g. global equation by Joyner and Boore (1988), Boore *et al.*, 1993; 1994) shows relatively good agreement between regional attenuations and used globally. No doubt, that lack of reliable regional GMPE is one of the biggest sources of uncertainty in this seismic hazard assessment.

In this study, all assessments of seismic hazard are based on two, more recent and well studied models of ground motion prediction equations.

The first applied GMPE of horizontal component (Atkinson and Boore, 2006), was developed for the central and eastern United States which is situated in a type of tectonic environment known as an intraplate region, or equivalently, stable continental area.

The second, considered as "classic" GMPE (one by Spudich *et al.*, 1999) is appropriate for predicting earthquake generated horizontal component of ground motions in extensional tectonic regimes. The area which is located between the Sierra Nevada Mountains in eastern California and the Wasatch Mountains in central Utah, are an example of shallow extensional tectonic environment. Some parts of Western Europe, parts of Italy and Greece, the East African Rift System are other examples of extensional environment. The relationships predict lower ground motions than any other applied ground motion prediction equation. One has to note, that in literature are known at least two updated versions of Spudich *et al.* (1999) GMAE, (Pankow and Pechmann, 2004; 2006).

Based on very limited number of PGA observations in the area and some macroseismic comparisons, based on exclusion criteria developed by Cotton *et al* (2006), we understand that of the four mentioned attenuation relationships, the one by Atkinson and Boore (2006), and one by Spudich *et al.* (1999) are most likely most appropriate to local conditions.

The two selected GMPEs, including their functional form and respective coefficients are provided in Appendix D.

9. Probabilistic Seismic Hazard Analysis for the Dam Site

In order to determine the seismic hazard curve for the site, i.e. probabilities of exceedance of specified values of PGA, the earthquake recurrence parameters obtained for each seismic source, together with the GMPE's are integrated. Details of the applied procedure are described in Appendix B.

Taking into account that very little is known about seismic potential of the four identified faults in vicinity of the dam site (Figure 7.2), two scenarios regarding their seismic activity were considered:

(a) the four faults identified in vicinity of the dam site are not active,

(b) all four faults are active, the sum, mean activity rate $\lambda = 0.01$ [eq/year], where activity rate refers to events with moment magnitude 4.0 and larger.

The respective seismic hazard curves (the annual probabilities of exceedance of median value of PGA at the site) for two considered GMPE-s and two seismic activity scenarios of four identified faults are shown in Figs 9.1(a)-(d). Figure 9.2(a)-(d) show the associated, respective return periods of specified values of median PGA.

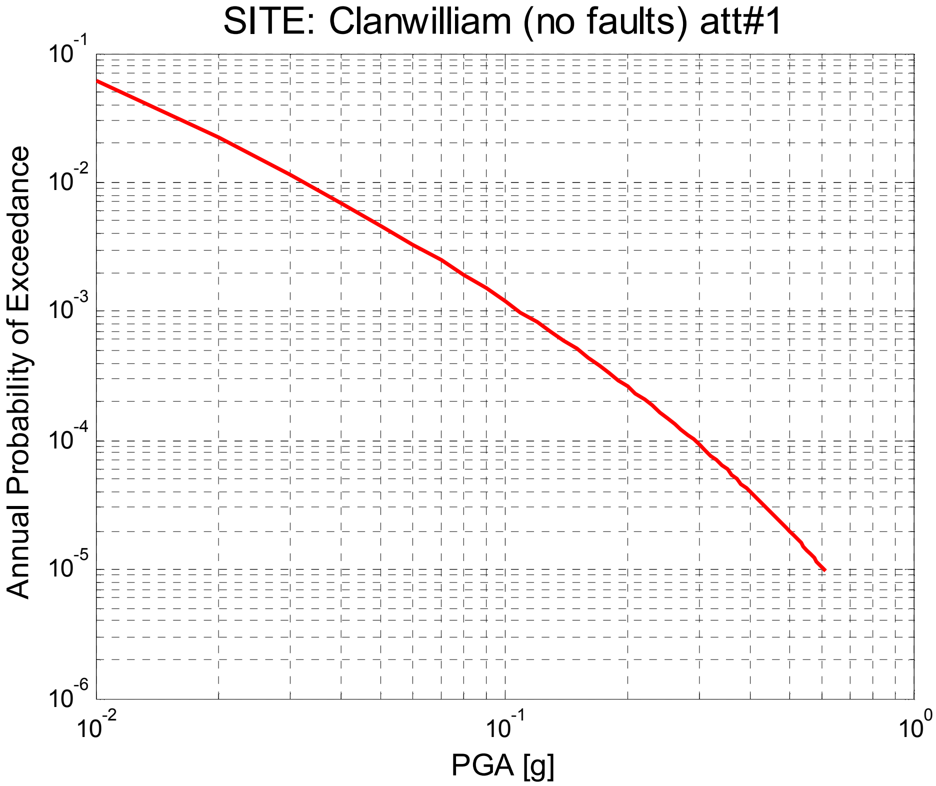


Figure 9.1(a) Annual probability of exceedance of median value of horizontal PGA at the site of the dam, calculated for ground motion prediction equation by Atkinson and Boore (2006), (GMPE-1). Scenario #1: four known faults in vicinity of the dam are not active.

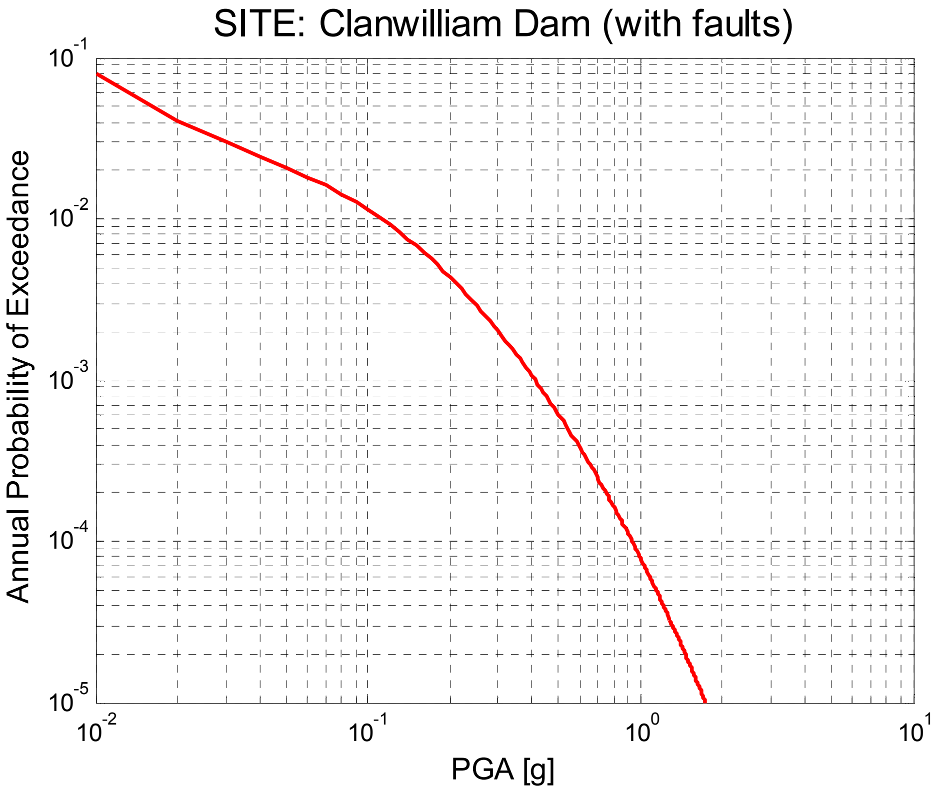


Figure 9.1(b) Annual probability of exceedance of median value of horizontal PGA at the site of the dam, calculated for ground motion prediction equation by Atkinson and Boore (2006), (GMPE-1). Scenario #2: four known faults in vicinity of the dam are active.

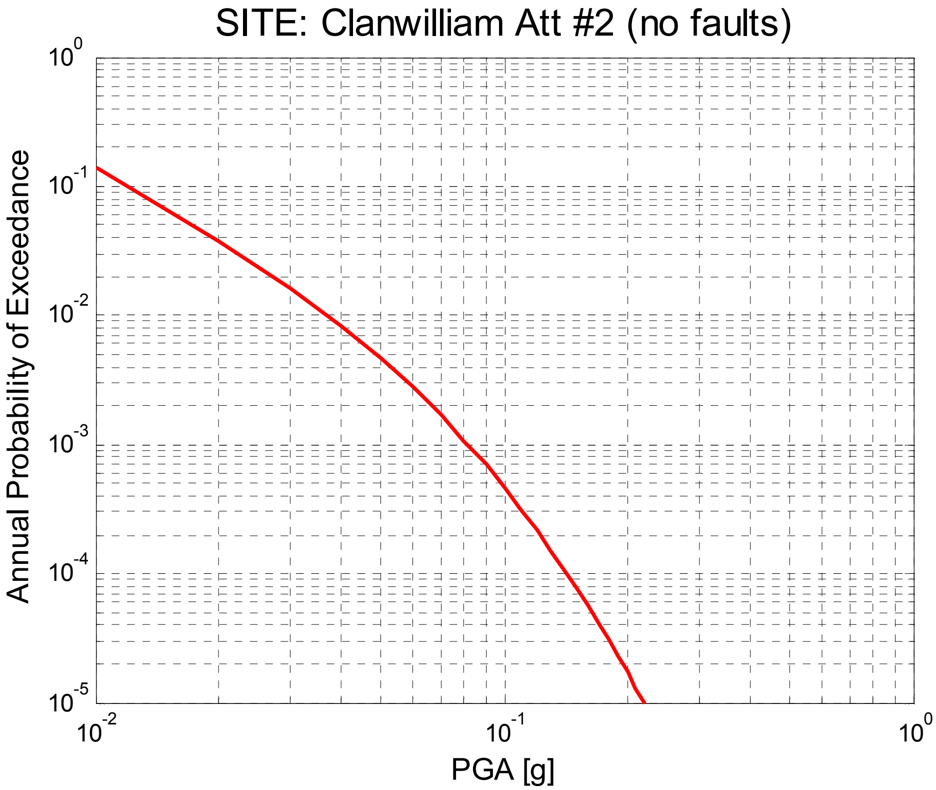


Figure 9.1(c) Annual probability of exceedance of median value of horizontal PGA at the site of the dam, calculated for ground motion prediction equation by Spudich *et al.* (1999), (GMPE-2). Scenario #1: four known faults in vicinity of the dam are not active.

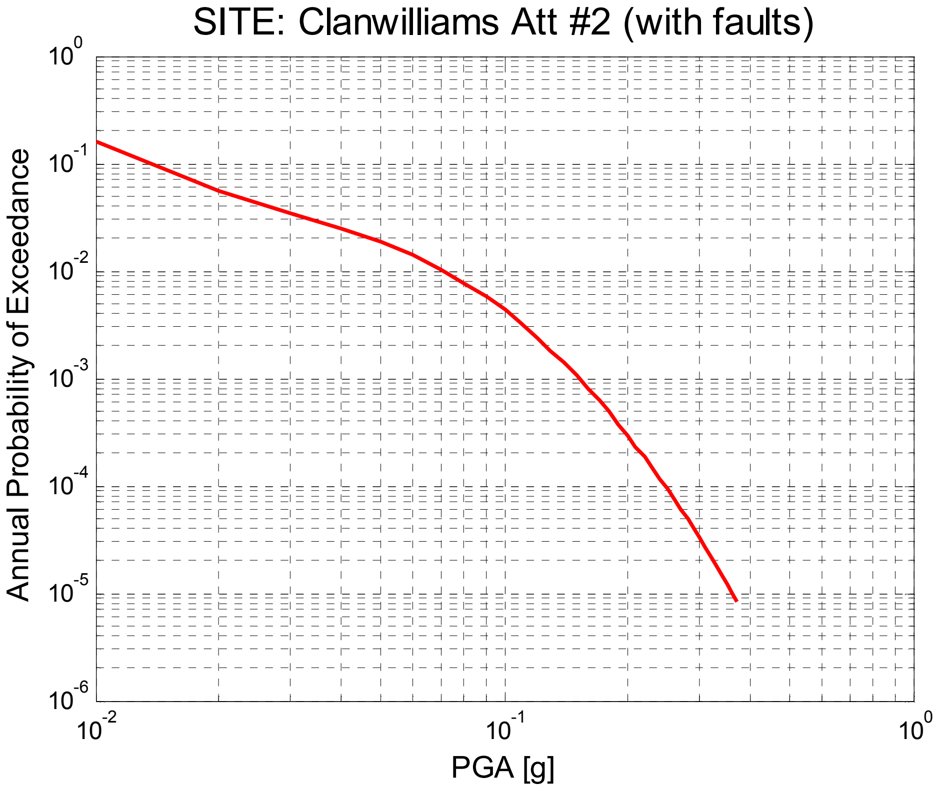


Figure 9.1(d) Annual probability of exceedance of median value of horizontal PGA at the site of the dam, calculated for ground motion prediction equation by Spudich *et al.* (1999), (GMPE-2). Scenario #2: four known faults in vicinity of the dam are active.

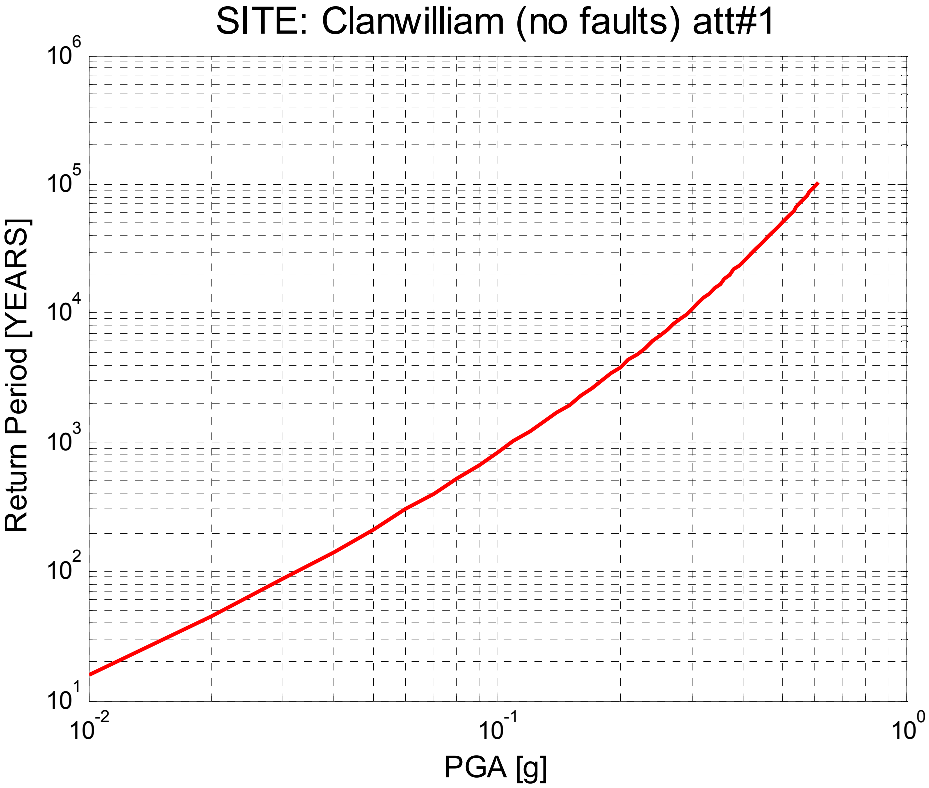


Figure 9.2(a) Mean return period of median value of horizontal PGA at the site of the dam, calculated for ground motion prediction equation by Atkinson and Boore (2006), (GMPE-1). Scenario #1: four known faults in vicinity of the dam are not active.

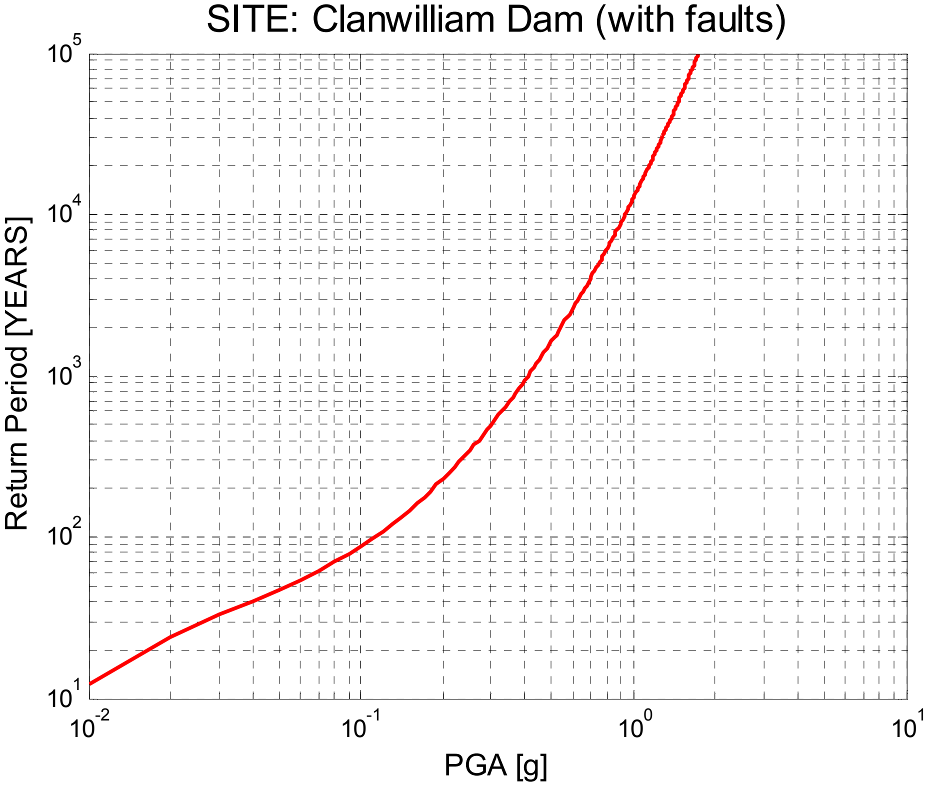


Figure 9.2(b) Mean return period of median value of horizontal PGA at the site of the dam, calculated for ground motion prediction equation by Atkinson and Boore (2006), (GMPE-1). Scenario #2: four known faults in vicinity of the dam are active.

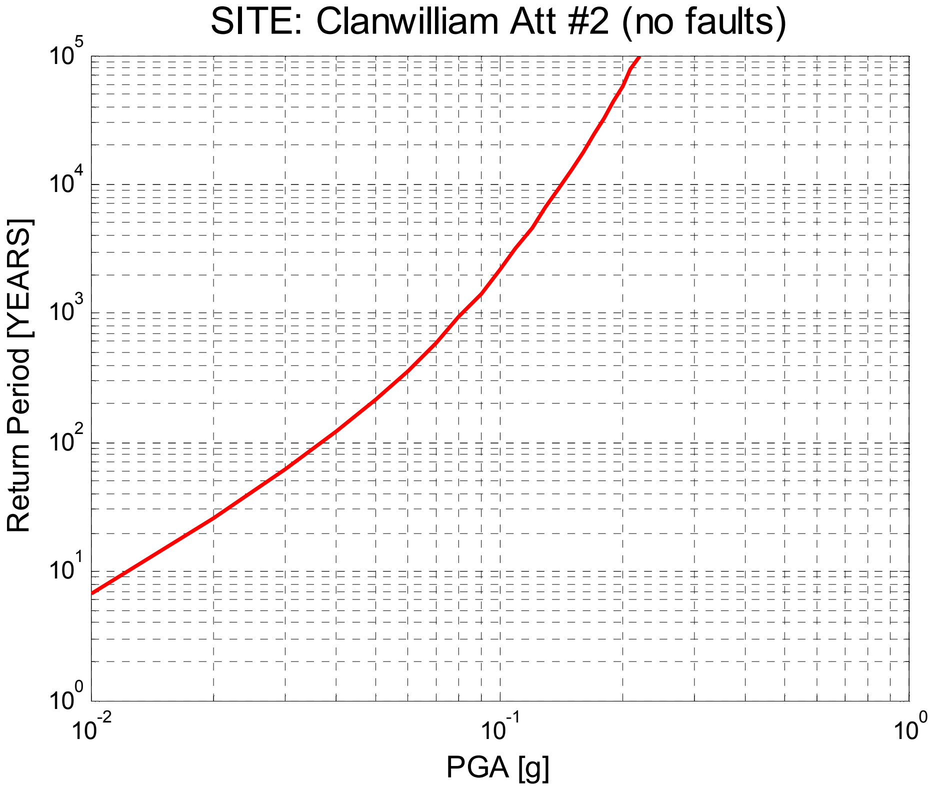


Figure 9.2(c) Mean return period of median value of horizontal PGA at the site of the dam, calculated for ground motion prediction equation by Spudich *et al.* (1999), (GMPE-2). Scenario #1: four known faults in vicinity of the dam are not active.

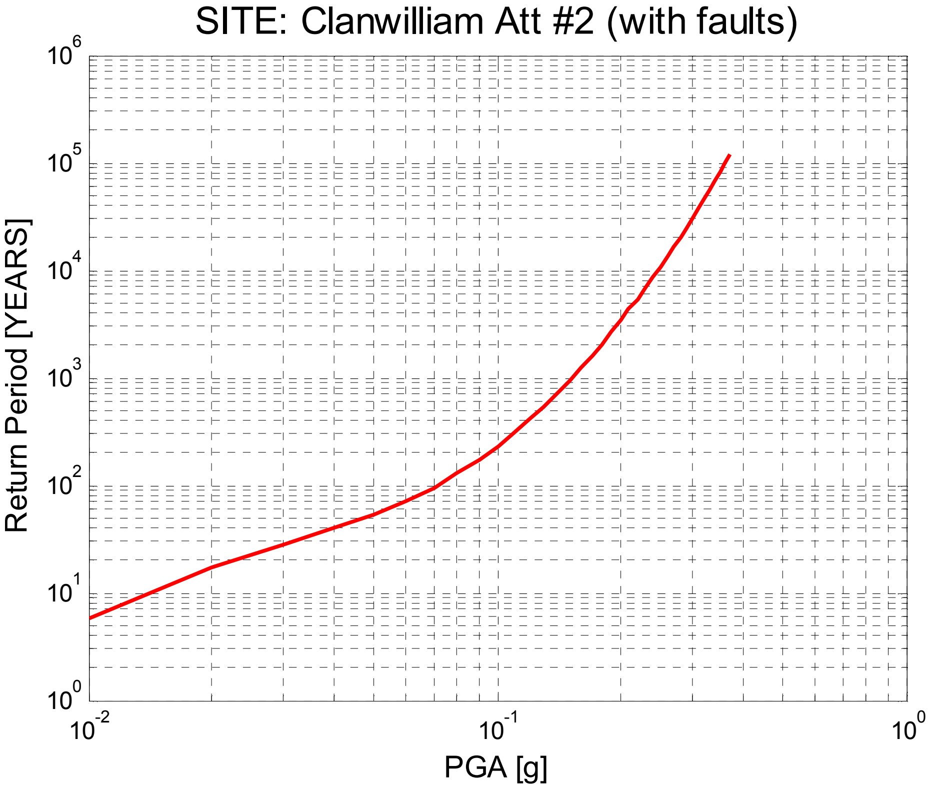


Figure 9.2(d) Mean return period of median value of horizontal PGA at the site of the dam, calculated for ground motion prediction equation by Spudich *et al.* (1999), (GMPE-2). Scenario #2: four known faults in vicinity of the dam are active.

All above results are also listed in the Appendix E. Simple conversion procedure of above results from *horizontal* to *vertical* component of PGA is described in Appendix F.

9.1 Maximum Credible Earthquake (MCE), Maximum Design Earthquake (MDE) and Operating Basis Earthquake (OBE).

The *Maximum Credible Earthquake* (MCE) is the largest conceivable earthquake that appears possible along a recognized fault or within a geographically defined tectonic province, under the presently known or presumed tectonic framework. In this report MCE is defined, as PGA having a return period of 10,000 years, or equivalently, 0.5% probability of exceedance in 50 years. The selected time period of 10,000 years is standard for critical structures for areas with low to moderate seismicity, ICOLD (1989).

The *Operating Basis Earthquake* (OBE) represents the level of ground motion at the dam site at which only minor damage is acceptable. The dam operation should remain functional and damage easily repairable from the occurrence of earthquake shaking not exceeding the OBE (ICOLD, 1989; *Engineering and Design*, ER 1110, 1995). The quoted documents specifies that for civil works projects like a Clanwilliam Dam, one could use for the OBE a 50% probability of not being exceeded in 100 years, or equivalently, PGA with return period of 144 years.

The *Maximum Design Earthquake* (MDE) is the maximum level of ground motion for which a structure is designed. The associated performance requirement is that the structure performs without catastrophic failure, although severe damage or economic loss may be tolerated. For critical structures, the MDE is the same as the MCE. For all other structures (like a Clanwilliam Dam), the MDE can be selected lower than the MCE (*Engineering and Design*, ER 1110-2-1806; 1995). In this report MDE is defined as earthquake with return period of 475 years, or equivalently as PGA with 10% probability of exceedance within 50 years.

Table 9-1 lists the OBE, MDE and MCE estimates for four considered cases: (the two GMPE-s and two scenarios of seismic potential of faults in vicinity of the dam). The OBE values fall within range of 0.04g - 0.15g. The MDE values fall within range 0.08.g - 0.29g and MCE values fall within range of 0.14g to 0.93g. **The value of MCE equal to 0.93g, predicted by GMPE #1 by Atkinson and Boore (2006), in case of active faults in vicinity of the dam, seems to be unrealistically high.**

Table 9-1 OBE, MDE and MCE estimates (horizontal component) for four considered cases

.

	Return Period [y]	**PGA [g]** **GMPE-1 Scenario#1 (faults are not active)**	**PGA [g]** **GMPE-1 Scenario#2 (faults are active)**	**PGA [g]** **GMPE-2 Scenario#1 (faults are not active)**	**PGA [g]** **GMPE-2 Scenario#1 (faults are active)**
OBE	Return period of 144 years (equivalent to 50% probability in 100 years)	0.04	0.15	0.04	0.08
MDE	Return period of 475 years (equivalent to 10% probability in 50 years)	0.08	0.29	0.06	0.13
MCE	Return period of 10 000 years	0.29	0.93	0.14	0.25

9.2 Newmark-Hall Elastic Response Spectra

Elastic design response spectra provide a basis for computing design displacements and forces in systems expected to remain elastic during earth shaking.

Horizontal, 5% damping elastic design spectra were calculated using PGA's listed in Table 9-1 by application of the Newmark and Hall (1982) procedure. These spectra are shown in 9.3(a)-(d). The spectra are anchored at the OBE, MDE and MCE values of PGA respectively.

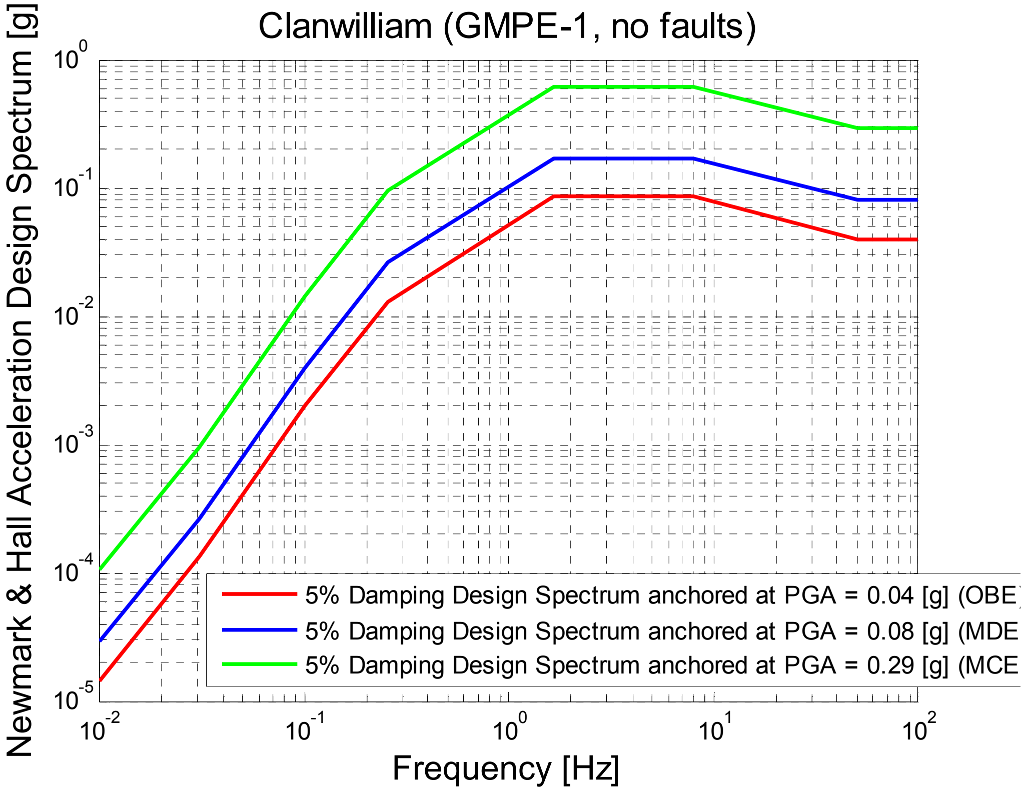


Figure 9.3(a). Newmark-Hall elastic design spectra anchored at the OBE, MDE and MCE values of horizontal PGA, calculated for ground motion prediction equation by Atkinson and Boore (2006), (GMPE-1). Scenario #1: four known faults in vicinity of the dam are not active.

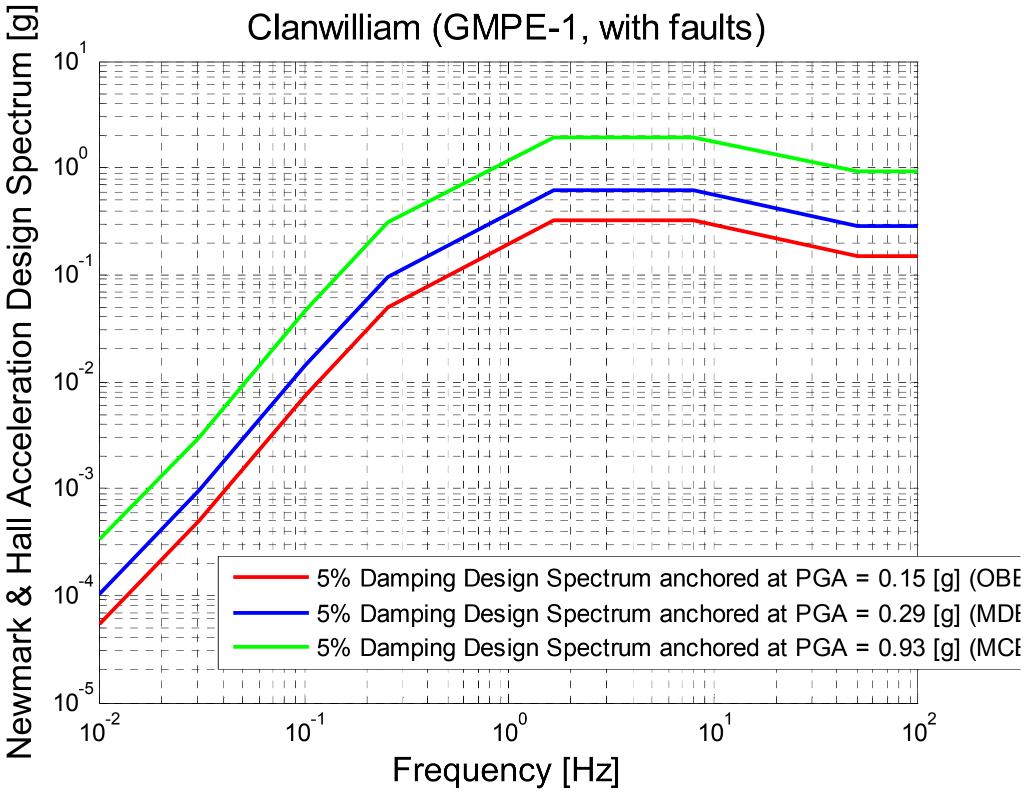


Figure 9.3(b). Newmark-Hall elastic design spectra anchored at the OBE, MDE and MCE values of horizontal PGA calculated for ground motion prediction equation by Atkinson and Boore (2006), (GMPE-1). Scenario #2: four known faults in vicinity of the dam are active.

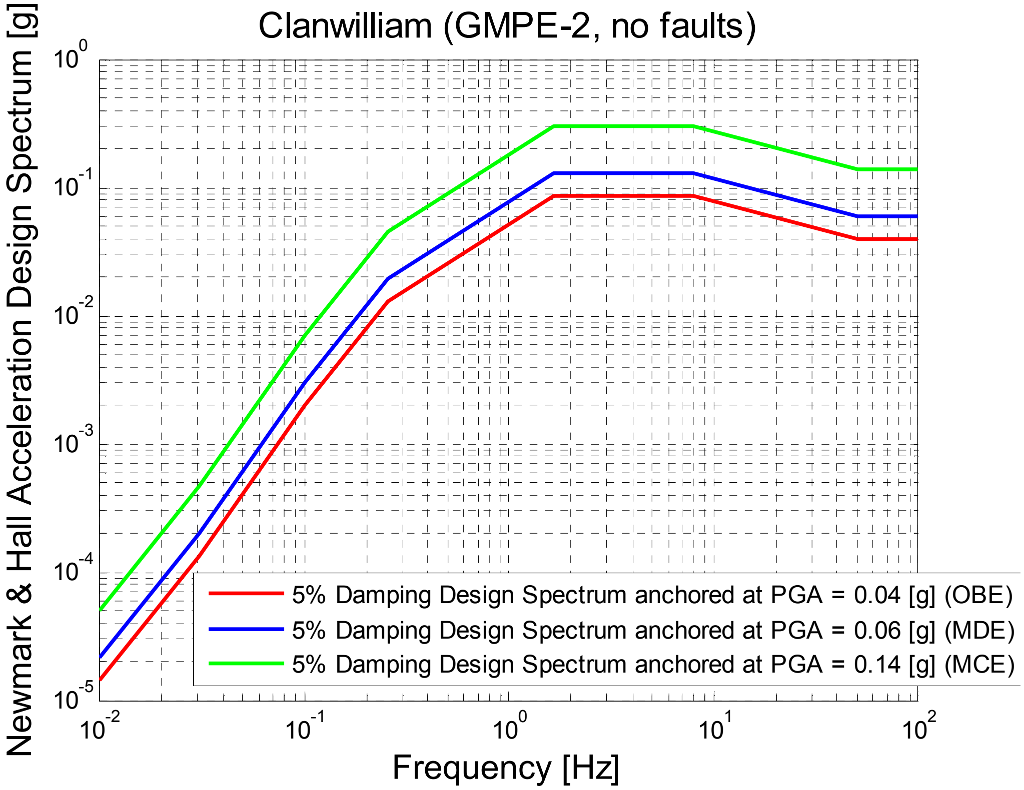


Figure 9.3(c). Newmark-Hall elastic design spectra anchored at the OBE, MDE and MCE values of horizontal PGA calculated for ground motion prediction equation by Spudich *et al.* (1999), (GMPE-2). Scenario #1: four known faults in vicinity of the dam are not active.

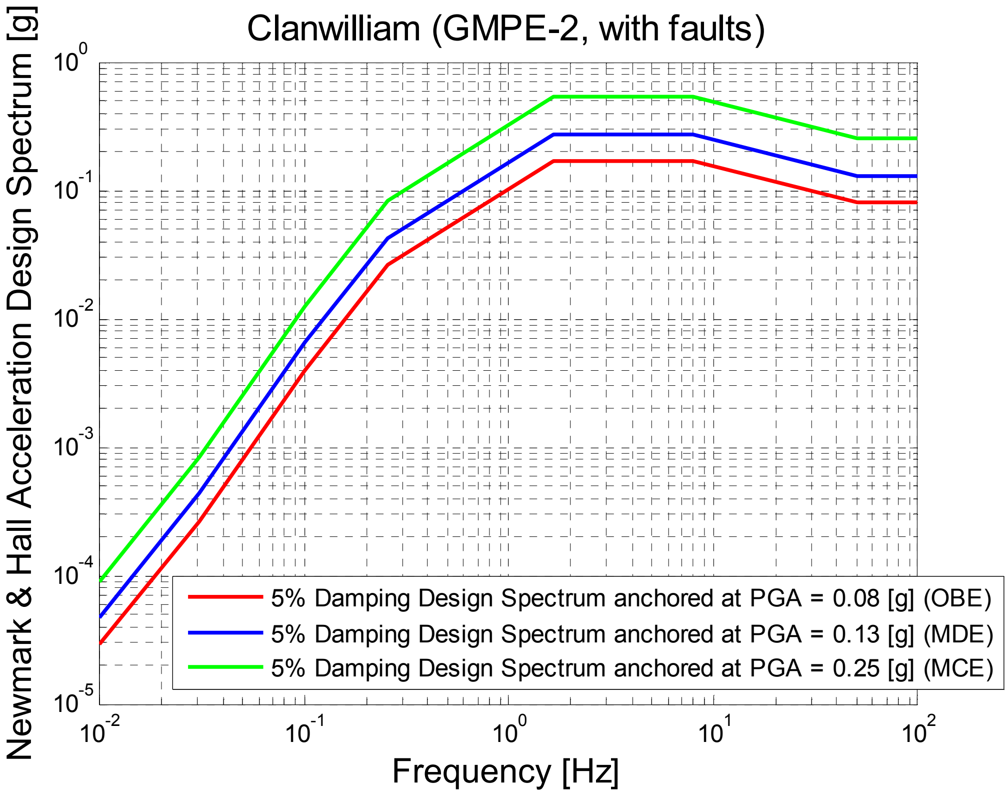


Figure 9.3(d). Newmark-Hall elastic design spectra anchored at the OBE, MDE and MCE values of horizontal PGA calculated for ground motion prediction equation by Spudich *et al.* (1999), (GMPE-2). Scenario #2: four known faults in vicinity of the dam are active.

9.3 Uniform Hazard Spectra (UHS)

The Uniform Hazard Spectrum (UHS) represents a constant probability or uniform hazard (response) spectrum. Essentially, it shows ground motion amplitudes over a number of oscillator periods of engineering interest at the same return period or probability of exceedance.

The Uniform Hazard Spectrum, (UHS), known also as uniform acceleration response spectrum is actually a lateral slice of an ensemble of hazard curves for a given probability of exceedance (or equivalent return period), where each curve represents acceleration at a particular frequency.

The UHS does not reflect the shape of spectrum of any particular earthquake, but provides combination of contributions from distant large magnitude events and nearer, smaller ones. This is a drawback if the spectrum is to be used directly for multi-mode analysis or to generate a strong motion record. However, for normal buildings, in low seismicity areas, the main need is to provide a single, frequency dependent indicator of lateral strength requirement, for which refinement of considering multi-modes is not necessary. Moreover, the UHS can be used as an envelope criterion for the spectra from a set of real time histories which can be used in more advanced designs.

The Figure 9.4(a)-(b) shows horizontal UHS for the Clanwilliam Dam site, calculated for two scenarios of seismic potential faults identified in vicinity of the dam. The calculations are based on GMPE by Atkinson-Boore (2006). Uniform hazard acceleration spectra based on GMPE-2 cannot be calculated since authors of the GMPE-2 (Spudich *et al.,*1999), provide parameters of spectral velocity, not spectral acceleration). Two scenario-characteristic horizontal UHS are calculated as a function of ground motion vibration frequency for 3 probabilities of annual exceedance: 0.5%, 0.1% and 0.01%. The same spectra calculated for 7 return periods: 100, 200, 475, 1,000, 10,000, 100,000 and a million years expressed in terms of both ground motion vibration frequency and ground motion vibration period are shown in Appendix E.

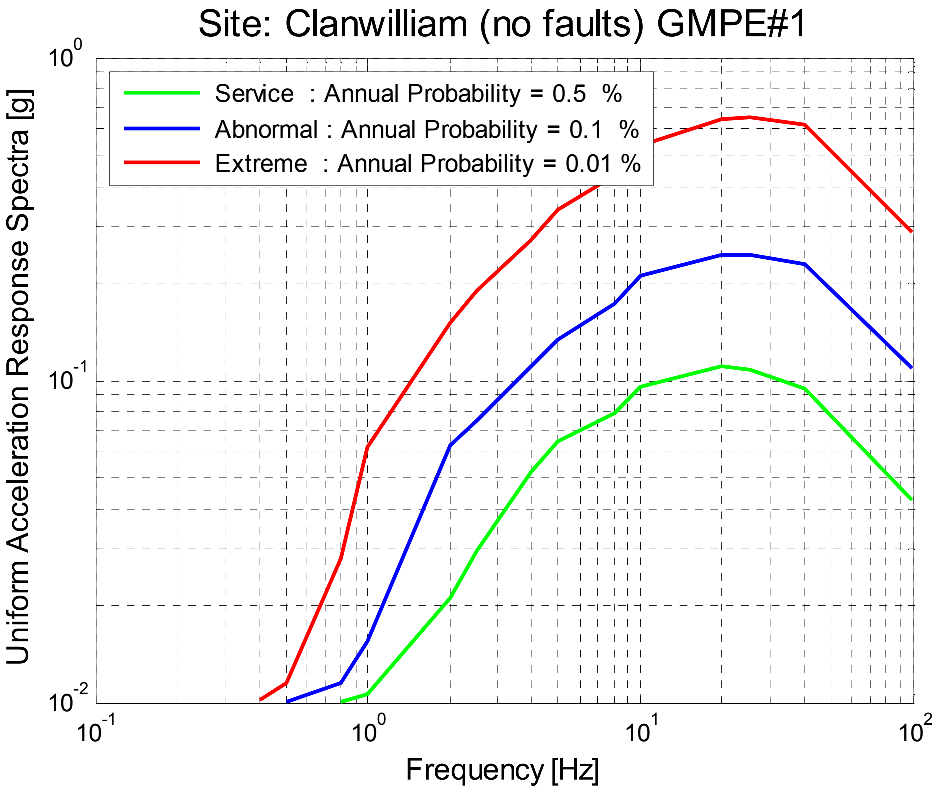


Figure 9.4(a). Horizontal Uniform Acceleration Response Spectra in terms of ground motion vibration frequency, calculated for GMPE by Atkinson and Boore (2006), (GMPE-1). Scenario #1: four known faults in vicinity of the dam are not active.

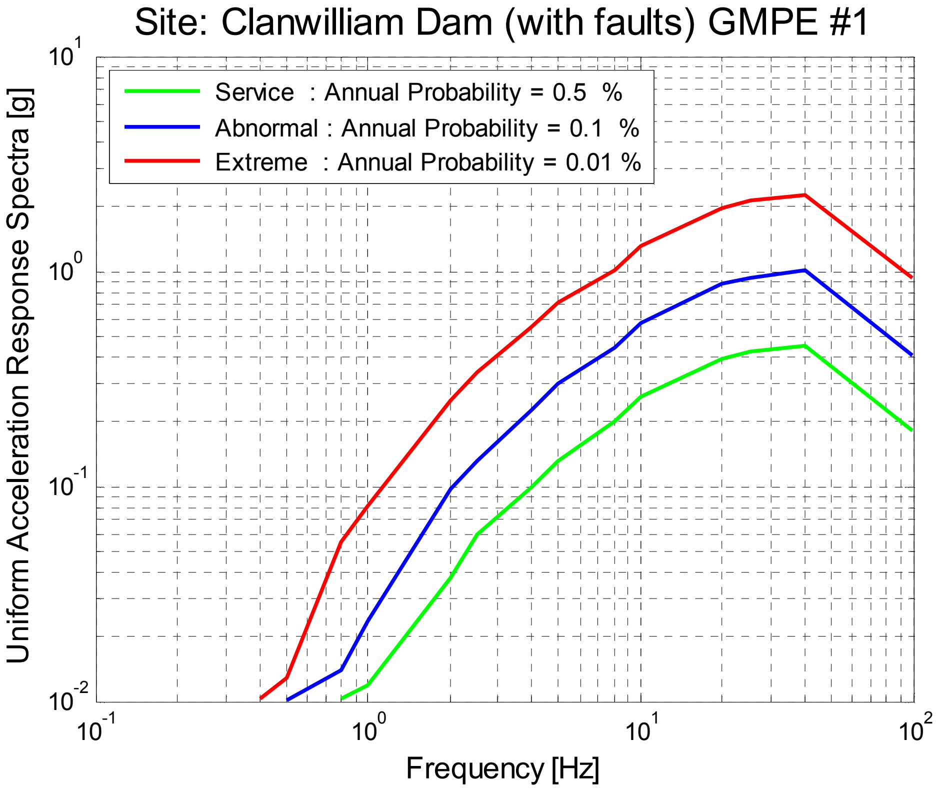


Figure 9.4(b). Horizontal Uniform Acceleration Response Spectra in terms of ground motion vibration frequency, calculated for GMPE by Atkinson and Boore (2006), (GMPE-1). Scenario #2: four known faults in vicinity of the dam are active.

10. Account of Uncertainties: Logic Tree Approach

The purpose of this section is to provide an interpretation of the uncertainties associated with the PSHA assessment performed for the site of the Clanwilliam Dam.

The development of any complexity seismotectonic model needed by PSHA requires several essential assumptions about its parameters, parameters which are uncertain and allow a wide range of interpretations.

There are two types of uncertainty (variability) that can be included in PSHA. These are aleatory and epistemic (e.g. Budnitz *et al*., 1997; Bernreuter *et al*., 1989).

Aleatory variability is uncertainty in the data used in an analysis which accounts for randomness associated with the prediction of a parameter from a specific model, assuming that the model is correct. For example, standard deviation of the mean value of ground motion represents typical aleatory variability. Aleatory variability is included, by default, in the PSHA calculations by means of mathematical integration, which are an integral part of the applied methodology.

Epistemic variability accounts for incomplete knowledge in the predictive models and the variability in the interpretations of the data. Epistemic uncertainty is included in the PSHA by account of alternative hypothesis and models. For example, the alternative hypothesis accounts for uncertainty in earthquake source zonation, their seismic potential, seismic source hazard parameters and GMPE's.

The lack of the reliable regional ground motion prediction equation and lack of knowledge of seismic potential of four identified faults in vicinity of the dam wall (Figure 7-2), are the main sources of uncertainty in this PSHA assessment for the site of a Clanwilliam Dam. For this reason the effect of several alternative assumptions regarding GMPEs and seismic potential of the faults is investigated in detail.

In this report, two models of horizontal component of GMPEs have been apply

- Atkinson and Boore, 2006 [GMPE-1], and
- Spudich *et al*., 1999 [GMPE-2].

The well known GMPE-1 by Atkinson and Boore, (2006) was developed for the central and eastern United States which is situated in a type of tectonic environment known as an intraplate region, or equivalently, stable continental area.

The GMPE-2 by Spudich *et al*. (1999) has been developed for estimation earthquake generated ground motions in extensional tectonic regimes. The East African Rift system is an example of a shallow extensional tectonic environment. The GMPE is well known and usually it predicts lower ground motions than any other ground motion prediction equation.

Let us apply formalism of the logic tree to the two GMPE's and uncertainty of seismic potential of identified faults in vicinity of the dam wall and calculate the horizontal PGA corresponding to the Operating Basis Earthquake (OBE), Maximum Design Earthquake (MDE), and Maximum Credible Earthquake (MCE).

Let us assume that that the probability of being correct for each one of the two GMPE's is: 0.50 (GMPE-1) and 0.50 (GMPE-2).

Following information provided by the Client, the subsequent assumptions were made regarding seismic potential of four identified faults in vicinity of the dam:

Probability [faults are not active] = **0.5**
Probability [faults are active] = **0.5.**

Based on the logic tree formalism and Table 9-1, the expected values and standard deviations of horizontal component of OBE, MDE and MCE for the site of Clanwilliam Dam are:

PGA (OBE. Return Period 144 years) =
0.5 * 0.5 * 0.04g + 0.5 * 0.5 * 0.15g + 0.5 * 0.5 * 0.04g + 0.5 * 0.5 * 0.08g =
0.078±0.045g

PGA (MDE. Return Period 475 years) =
0.5 * 0.5 * 0.08g + 0.5 * 0.5 * 0.29g + 0.5 * 0.5 * 0.06g + 0.5 * 0.5 * 0.13g =
0.140±0.090g

PGA (MCE. Return Period 10,000 years) =
0.5 * 0.5 * 0.29g + 0.5 * 0.5 * 0.93g + 0.5 * 0.5 * 0.14g + 0.5 * 0.5 * 0.25g =
0.402±0.309 g

It is important to note that the map of seismic hazard for South Africa (Kijko *et al.*, 2003) shows value of MDE ca. 0.1g, which is less than computed above (0.014g). But the same time, if uncertainty of the estimated value of MDE is taken into account, the map MDE value is within the range mean +/- standard deviation which is <0.05g-0.23g>. Of course the resolution of the hazard map is too low and it can be used only as guidance.

Figure 9.4 (c) shows effect of application of logic tree formalism to the uniform, horizontal ground motion acceleration spectra, Figure 9.4 (a)-(b), after assumption that probabilities that faults are active(scenario #2) and not active (scenario #1) are the same and equal 0,5. The resulting uniform ground acceleration spectra are shown in Figure 9.4 (c). The service, abnormal and extreme curves show a spectral acceleration peak of approximately 0,3g, 0,6g and 1,6g at 40 Hz, respectively.

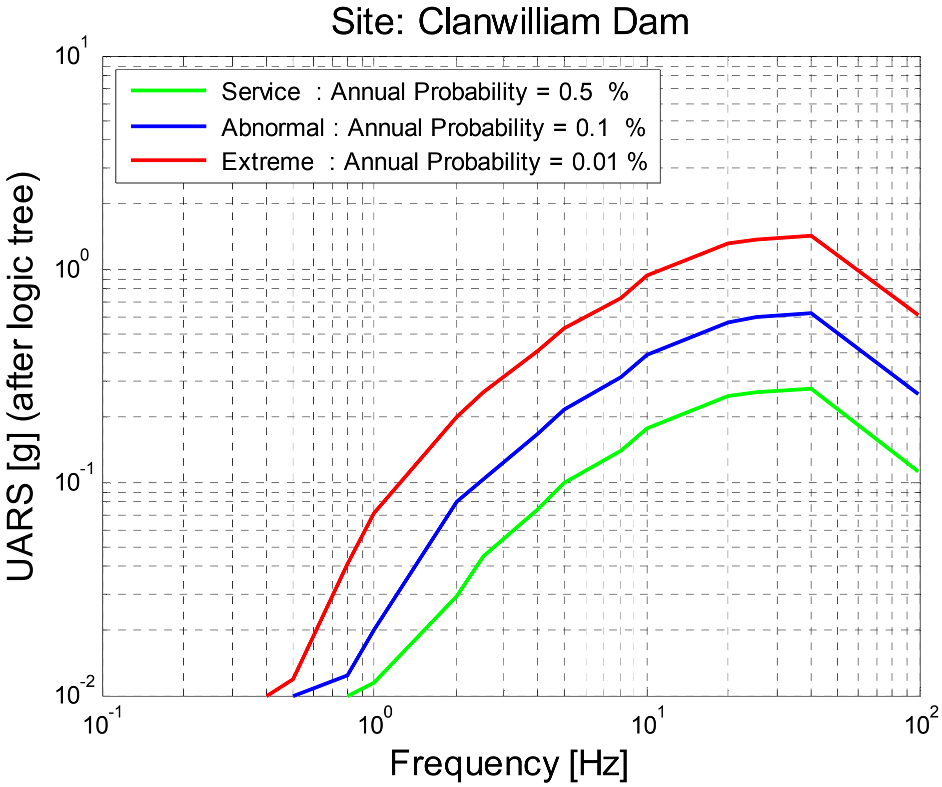


Figure 9.4 (c) Effect of application of logic tree formalism to the uniform horizontal ground motion acceleration spectra shown in Figure 9.4 (a)-(b). It was assumed that probabilities that faults are active (scenario #2) and not active (scenario #1) are the same and equal to 0,5.

11. Conclusions

The PSHA was performed using the conventional, Cornell-McGuire procedure (Cornell, 1968; McGuire, 1976, 1978). The earthquake recurrence parameters *b*-value, λ, and $m_{\max}$ were calculated by the procedure of Kijko and Sellevoll (1989, 1992) and Kijko (2004).

The applied procedure requires knowledge of regional geology, tectonics, paleo-historic and instrumentally recorded seismicity. Such information was provided by client. Unfortunately the provided information is highly incomplete. The incompleteness of geological model of the area contributes to the uncertainties of PSHA assessment.

All calculations are repeated four times, each for two considered ground motion prediction equations and two different assumptions about seismic potential of four faults identified in vicinity of the dam wall.

The uncertainties have been taken into account thorough logic tree formalism. The logic tree allows inclusions of alternative scenarios and interpretations that are weighted according to their probability of being correct.

Following the international guidance, (ICOLD, 1989; *Engineering and Design*, ER 1110, 1995), three designed levels of PGA were considered, Operating Basis Earthquake, OBE, (return period 144 years), Maximum Credible Earthquake, MCE (return period 475 years), and the Maximum Design Earthquake, MDE (10,000 years). The estimated value of MDE (0.14g) is slightly higher than MDE (ca. 0.1g) predicted by seismic hazard map of SA (Kijko *et al.*, 2003). However, if uncertainty of the estimated value of MDE is taken into account, the map value is within the range mean +/- standard deviation, which is <0.05g-0.23g>.

The uniform acceleration response spectra and 5% damping the Newmark-Hall elastic design spectra are also provided.

The lack of the regional ground motion prediction equation and information about seismic potential of four faults identified in vicinity of the dam site are the main sources of uncertainty in this PSHA assessment for the planned Clanwilliam Dam. The uncertainty can be significantly reduced by implementation of results of additional geological investigation on the site.

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Appendix A

Seismicity of area surrounding Clanwilliam Dam site

year	month	day	lat	long	magnitude
1620	4	7	-33.80	18.40	3.70
1690	6	15	-33.90	18.40	3.70
1695	10	4	-33.90	18.40	3.70
1696	1	11	-33.90	18.40	3.70
1739	9	5	-33.90	18.40	3.70
1749	8	27	-33.90	18.40	3.00
1766	7	14	-34.20	18.50	4.30
1809	12	4	-34.00	18.40	6.30
1809	12	28	-33.90	18.40	3.70
1810	1	29	-33.90	18.40	3.00
1810	4	11	-33.90	18.40	3.70
1810	12	26	-34.10	19.50	3.00
1811	1	7	-33.90	18.40	3.00
1811	6	2	-33.90	18.40	5.70
1811	6	19	-33.90	18.40	5.00
1819	4	14	-30.30	18.10	4.30
1819	6	24	-32.90	18.80	3.00
1826	6	15	-33.00	18.00	3.70
1826	4	14	-33.90	18.40	3.00
1835	11	11	-33.90	18.40	4.30
1857	8	14	-33.50	19.00	5.00
1869	10	31	-33.90	18.40	3.70
1869	11	23	-30.00	17.20	3.70
1882	4	29	-29.70	17.90	3.70
1884	7	11	-30.60	21.40	3.00
1885	5	10	-33.90	18.40	3.00
1899	9	13	-33.90	18.40	5.00
1902	5	28	-33.90	18.40	4.30
1903	7	9	-33.90	18.40	3.70
1908	12	30	-29.70	17.90	4.00
1919	1	13	-31.40	19.80	3.00
1920	8	13	-33.90	18.50	3.00
1921	2	19	-31.60	18.70	3.70
1921	10	9	-33.30	19.10	5.00
1922	1	3	-33.30	19.10	3.70
1924	2	22	-34.00	18.40	3.00
1926	8	11	-33.40	18.40	4.00
1937	8	19	-33.40	18.40	3.00
1941	10	23	-31.00	17.70	4.30
1947	2	27	-32.80	17.80	3.70
1950	9	30	-30.50	18.00	5.50
1950	11	19	-34.00	18.00	4.20
1952	1	26	-32.90	20.50	4.90
1952	1	26	-32.90	20.50	4.60
1952	1	26	-32.90	20.50	4.30
1952	1	27	-32.90	20.50	5.00
1952	1	27	-33.00	20.50	5.30
1952	1	28	-33.00	20.50	4.00
1952	1	28	-32.90	20.50	5.40
1952	1	28	-32.90	20.50	5.00
1952	1	29	-32.90	20.50	4.70
1952	2	1	-32.90	20.50	4.90
1952	2	26	-34.00	20.40	4.20
1952	5	13	-32.90	20.50	4.40
1953	2	26	-30.00	21.00	4.40
1957	9	20	-34.00	18.20	4.20

1957	9	30	-34.00	18.20	4.20
1960	8	29	-33.40	19.30	4.80
1963	8	27	-33.10	19.00	5.00
1963	9	17	-33.30	19.30	4.80
1964	2	21	-34.10	18.00	4.30
1966	3	1	-34.10	18.00	4.30
1966	7	31	-30.00	19.00	4.20
1967	6	16	-30.40	18.40	4.30
1967	7	12	-30.00	20.00	3.70
1968	2	24	-30.20	20.00	3.60
1969	9	11	-33.40	21.00	5.20
1969	9	29	-33.20	19.20	3.70
1969	9	29	-33.10	19.30	3.50
1969	9	29	-33.28	19.24	6.30
1969	9	29	-33.20	19.20	3.90
1969	9	29	-33.20	19.40	3.50
1969	9	29	-33.20	19.10	3.40
1969	9	29	-33.10	19.40	3.50
1969	9	29	-33.10	19.40	3.50
1969	9	29	-33.40	19.30	3.50
1969	9	29	-33.40	19.40	3.80
1969	9	29	-33.40	19.40	3.40
1969	9	29	-33.40	19.40	3.30
1969	9	29	-33.40	19.40	3.70
1969	9	29	-33.00	19.10	4.30
1969	9	30	-33.00	19.10	3.40
1969	9	30	-33.30	19.20	3.90
1969	9	30	-33.30	19.20	3.70
1969	9	30	-33.30	19.20	3.90
1969	9	30	-33.30	19.20	3.90
1969	9	30	-33.30	19.20	3.50
1969	9	30	-33.30	19.20	3.90
1969	9	30	-33.10	19.00	4.20
1969	9	30	-33.10	19.00	3.90
1969	9	30	-33.00	20.10	3.90
1969	9	30	-33.40	19.20	4.50
1969	9	30	-33.10	19.40	3.80
1969	9	30	-33.10	19.40	3.40
1969	10	1	-33.50	19.40	4.10
1969	10	1	-33.50	19.40	3.40
1969	10	2	-33.50	19.40	3.40
1969	10	2	-33.50	19.40	3.40
1969	10	2	-33.50	19.40	4.10
1969	10	3	-33.50	19.40	4.00
1969	10	3	-33.50	19.40	3.40
1969	10	3	-33.40	19.20	4.70
1969	10	5	-33.40	19.30	5.10
1969	10	5	-33.40	19.30	3.50
1969	10	6	-33.40	19.30	3.90
1969	10	6	-33.30	19.20	4.40
1969	10	8	-32.20	19.20	3.80
1969	10	8	-32.20	19.20	4.10
1969	10	10	-33.20	19.30	4.80
1969	10	11	-33.20	19.00	4.10
1969	10	11	-33.20	19.00	3.70
1969	10	13	-33.20	19.00	3.40
1969	10	13	-33.20	19.00	3.40
1969	10	19	-33.20	19.00	3.70
1969	11	5	-33.40	19.40	5.40
1969	11	6	-33.40	19.40	3.40
1969	11	6	-33.30	19.10	4.30
1969	11	8	-33.30	19.00	3.80
1969	11	8	-33.30	19.20	4.30
1969	11	8	-33.30	19.20	4.20
1969	11	9	-33.30	19.20	4.80
1969	11	9	-33.30	19.20	3.80
1969	11	9	-33.30	19.20	3.40
1969	11	9	-33.30	19.20	3.30
1969	11	9	-33.30	19.20	3.40
1969	11	9	-33.30	19.20	3.60
1969	11	9	-33.30	19.20	3.90

1969	11	9	-33.30	19.20	4.50
1969	11	9	-33.30	19.20	4.20
1969	11	9	-33.30	19.20	3.40
1969	11	9	-33.30	19.20	4.30
1969	11	9	-33.30	19.20	3.40
1969	11	9	-33.30	19.30	4.60
1969	11	10	-33.30	19.30	3.40
1969	11	10	-33.30	19.70	5.10
1969	11	10	-33.30	19.70	3.80
1969	11	10	-33.30	19.70	3.40
1969	11	10	-33.30	19.70	3.90
1969	11	11	-33.30	19.70	3.80
1969	11	12	-33.30	19.70	3.50
1969	11	13	-33.30	19.70	4.10
1969	11	13	-33.30	19.70	3.90
1969	11	16	-33.30	19.70	3.90
1969	11	17	-33.30	19.70	3.50
1969	11	19	-33.20	19.20	3.70
1969	11	23	-33.20	19.20	3.40
1969	12	4	-33.20	19.20	3.90
1969	12	6	-33.20	19.20	3.70
1970	4	6	-33.70	21.40	4.00
1970	4	14	-33.30	19.30	5.70
1970	4	14	-32.90	19.20	4.60
1970	4	14	-33.00	19.30	4.10
1970	4	14	-32.90	19.20	4.20
1970	4	16	-33.00	19.00	4.10
1971	9	28	-33.00	19.50	5.46
1973	1	12	-33.33	19.09	4.50
1974	12	19	-33.29	19.25	3.10
1974	12	23	-33.39	18.84	3.40
1977	3	2	-33.48	19.49	5.30
1977	3	2	-33.30	19.50	4.10
1977	4	28	-33.20	19.10	3.80
1977	6	7	-33.52	18.97	5.50
1978	4	11	-33.40	19.30	3.10
1981	3	20	-30.18	20.90	3.70
1981	8	24	-33.30	19.00	4.60
1982	11	3	-33.30	19.20	3.10
1983	2	24	-33.49	18.85	4.64
1987	3	5	-33.10	17.62	3.20
1987	4	21	-29.72	19.82	3.68
1987	4	26	-29.96	19.64	4.36
1987	4	27	-29.96	19.73	4.62
1987	9	26	-30.30	18.62	3.45
1987	12	11	-29.50	19.80	3.66
1988	8	5	-29.46	19.96	3.78
1991	6	3	-33.45	19.24	3.10
1991	6	24	-30.09	18.68	3.40
1991	8	11	-29.94	18.35	4.10
1991	10	31	-33.35	19.16	5.10
1993	3	11	-29.53	18.34	4.70
1993	6	3	-29.67	17.97	4.20
1993	11	20	-29.68	19.43	3.70
1994	7	15	-33.91	18.10	5.46
1994	12	31	-30.36	20.87	5.10
1995	2	27	-29.58	18.51	4.10
1996	2	4	-29.65	18.10	4.50
1996	4	26	-29.55	17.87	3.80
1996	9	15	-30.05	19.24	5.70
1998	10	5	-31.73	22.00	3.90
2001	3	24	-29.83	18.98	4.50
2001	4	6	-29.59	19.51	5.20
2002	11	18	-33.22	19.62	3.10
2002	11	18	-32.86	20.83	3.50
2003	5	19	-32.85	19.66	3.30
2003	9	30	-30.10	19.90	3.10
2003	10	22	-33.35	19.17	3.00
2003	11	10	-33.23	19.15	3.00
2003	12	12	-33.18	19.23	3.70
2003	12	12	-31.22	18.34	3.60

2004	8	9	-31.30	19.67	3.20
2004	9	16	-30.07	20.98	3.20
2004	10	10	-32.71	18.19	3.60
2004	10	27	-33.25	19.05	3.70
2005	1	17	-31.25	20.66	3.10
2006	9	27	-33.40	18.93	3.80

Appendix B

Applied Methodology for Probabilistic Seismic Hazard Analysis

1. Introduction

The essence of the Probabilistic Seismic Hazard Analysis (PSHA) is the calculation of the probability of exceedance of a specified ground motion level at a specified site (Cornell, 1968; Reiter, 1990). In principle, PSHA can address a very broad range of natural hazards associated with earthquakes, including ground shaking and ground rupture, landslide, liquefaction or tsunami. However, in most cases, the interest of designers is in the estimation of likelihood of a specified level of ground shaking, since it causes the greatest economic losses.

The typical output of the PSHA is **seismic hazard curve** (often, a set of seismic curves), i.e. plots of the estimated probability, per unit time, of the ground motion variable, e.g. peak ground acceleration (PGA) being equal to or exceeding the level as a function of PGA (Budnitz *et al*., 1997). The essence of the PSHA is that its product – the seismic hazard curve, quantifies the hazard at the site from all possible earthquakes of all possible magnitudes at all significant distances from the site of interest, by taking into account their frequency of occurrences. In addition to hazard curve, the output of PSHA includes results of the so called deaggregation procedure. The procedure provides information on earthquake magnitudes and distances that contribute to the hazard at a specified return period, and at a structural period of engineering interest (Budnitz *et al*., 1997).

In general, the standard PSHA procedure is based on two sources of information: (1) observed seismicity, recapitulated by seismic event catalogue, and (2) area-specific, geological data. After the combination of a selected model of earthquake occurrence with the information on the regional seismic wave attenuation or ground motion prediction equation (GMPE), a regional seismotectonic model of the area is formulated. In addition, the PSHA takes into account the site specific soil properties.

Complete PSHA can be performed only when information on the regional seismotectonic model and the site-specific soil properties are known.

Clearly, all above information, required by a complete PSHA is subjective and often, highly uncertain especially in stable continental areas where the earthquake activity is very low. According to convention established in the fundamental document by Budnitz *et al*. (1997), there are two types of uncertainties, associated with PSHA: these are **aleatory** and **epistemic** uncertainties. According to Budnitz *et al*. (1997), the uncertainties that are part of the applied model used in the analysis, are called aleatory uncertainties. The other names for the aleatory uncertainty are 'stochastic' or 'random' uncertainties. Even when the model is perfectly correct, and the numerical values of its parameters are known without any errors, aleatory uncertainties (for a given model) are still present (Budnitz *et al*. 1997).

The uncertainties which come from incomplete knowledge of the models, i.e. when wrong models are applied or/and the numerical values of their parameters are not known, are called epistemic uncertainties. As relevant information is collected, the epistemic uncertainties can be reduced (Budnitz *et al.*, 1997).

By definition of the PSHA procedure, the aleatory uncertainty is included in the process of PSHA calculations by means of applied models (statistical distributions) and by mathematical integration. Epistemic uncertainty can be incorporated in the PSHA by consideration of an alternative hypothesis (e.g. alternative boundaries of the seismic sources and their recurrence parameters), and alternative models (e.g. alternative earthquake distributions or/and application of alternative PGA attenuation equations). Incorporation of this type of uncertainties into the PSHA is performed by application of the logic tree formalism.

A complete PSHA includes an account of aleatory as well as epistemic uncertainties. Any PSHA without the incorporation of the above uncertainties is considered to be incomplete.

This Appendix concentrates on two major mathematical aspects of the PSHA:

(1) The procedure for assessment of the seismic source characteristic, recurrence parameters when the data are incomplete and uncertain. Use is made of the most common assumptions in engineering seismology i.e. those earthquake occurrences in time follow a Poisson process and that earthquake magnitudes are distributed according to a Gutenberg-Richter doubly-truncated distribution. Following the above assumptions, seismic source recurrence parameters: the mean seismic activity rate, λ (which is a parameter of the Poisson distribution); the level of completeness of the earthquake catalogue $m_{\min}$, the maximum regional earthquake magnitude $m_{\max}$, and the Gutenberg-Richter parameter b. To assess the above parameters, a seismic event catalogue containing origin times, size of seismic events and spatial locations is needed. The maximum seismic source characteristic earthquake magnitude $m_{\max}$ is of paramount importance in this approach; therefore a statistical technique that can be used for evaluating this important parameter is presented.

(2) PSHA methodology i.e. calculating the probability of exceedance of a specified ground motion level at a specified site. Often, the presented approach is known as the Cornell-McGuire procedure.

2. Estimation of the Seismic Source Recurrence Parameters – Bayesian Approach

This section gives an outline of the procedure used to determine the seismic source recurrence parameters: the mean seismic activity rateλ, the Gutenberg-Richter parameter *b,* and the maximum regional earthquake magnitude $m_{\max}$.

2.1 Nature of input data

The lack, or incompleteness, of data in earthquake catalogues is a frequent issue in a statistical analysis of seismic hazard. Contributing factors include the historical and socio–economic context, demographic variations and alterations in the seismic network. Generally, the degree of completeness is a monotonically increasing function of time, i.e. the more recent portion of the catalogue has a lower level of completeness. The methodology makes provision for the earthquake catalogue to contain three types of data: (1) very strong prehistoric seismic events (paleo-earthquakes), which usually occurred over the last thousands of years; (2) the macro-seismic observations of some of the strongest seismic events that occurred over a period of the last few hundred years; and (3) complete recent data for a relatively short period of time. The complete part of the catalogue can be divided into several sub-catalogues, each of which is complete for events above a given threshold magnitude $m_{\min}^{(i)}$, and occurring in a certain period of time T_i where $i = 1, \ldots, s$ and s is the number of complete sub-catalogues. The approach permits 'gaps' (T_g) when records were missing or the seismic networks were out of operation. Uncertainty in earthquake magnitude is also taken into account in that an assumption is made that the observed magnitude is true magnitude subjected to a random error that follows a Gaussian distribution having zero mean and a known standard deviation. Figure 2.1 depicts the typical scenario confronted when conducting seismic hazard assessments.

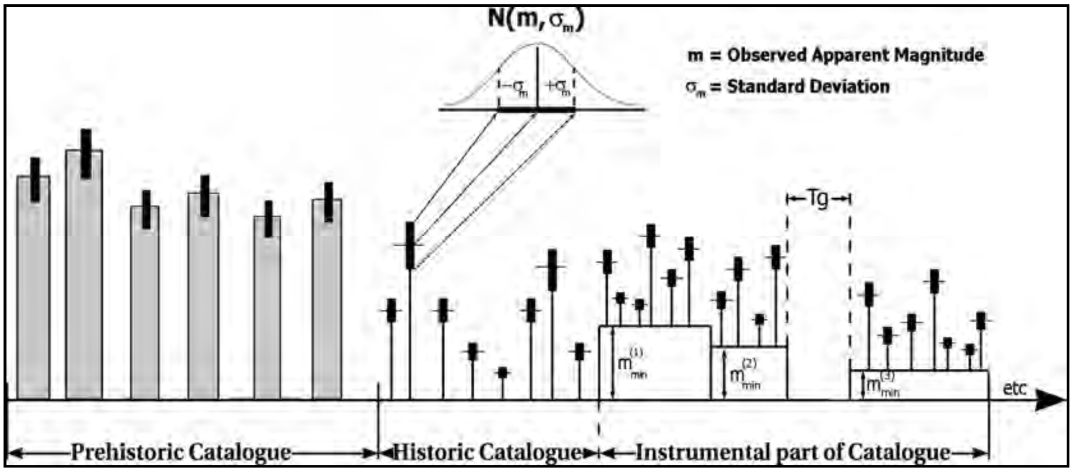

Figure 2.1 Illustration of data which can be used to obtain reccurence parameters for the specified seismic source. The approach permits the combination of the largest earthquakes (prehistoric/paleo- and historic) data and complete (instrumental) data having variable threshold magnitudes. It accepts 'gaps' (T_g) when records were missing or the seismic networks were out of operation. The procedure is capable of accounting for uncertainties of occurrence time of prehistoric earthquakes. Uncertainty in earthquake magnitude is also taken into account, in that an assumption is made that the observed magnitude, is true magnitude subjected to a random error that follows a Gaussian distribution having zero mean and a known standard deviation. (Modified after Kijko and Sellevoll, 1992)

2.2 Statistical preliminaries

Basic statistical distributions and quantities utilized in the development of the methodology are briefly described in what follows.

The Poisson distribution is used to model the number of occurrences of a given earthquake magnitude or a given amplitude of a selected ground motion parameter being exceeded within a specified time interval.

$$p(n|\lambda,t)=P(N=n|\lambda,t)=\frac{(\lambda t)^n}{n!}e^{-\lambda t} \quad n=0,1,2,... \tag{1}$$

Note that λ here refers to the mean of the distribution, and describes the mean activity rate (mean number of occurrences).

The gamma distribution, given its flexibility, is used to model the distribution of various parameters in our approach, and is given by

$$f(x) = (x)^{q-1}\frac{p^q}{\Gamma(q)}e^{-px}, \qquad x>0 \ , \tag{2}$$

where $\Gamma(q)$ is the gamma function defined as

$$\Gamma(q) = \int_0^\infty y^{q-1}e^{-y}dy, \quad q>0\,, \tag{3}$$

The parameters p and q are related to the mean μ, and variance σ^2, of the distribution according to

$$\mu_x = \frac{q}{p}\ , \tag{4}$$

$$\sigma_x{}^2 = \frac{q}{p^2}, \tag{5}$$

The coefficient of variation expresses the uncertainty related to a given parameter, and is given by

$$COV_x = \frac{\sigma_x}{\mu_x}, \tag{6}$$

thus describing the variation of a parameter relative to its mean value, with a higher value indicating a greater dispersion of the parameter.

2.3 Estimation of the seismic source recurrence parameters

The standard assumption adopted is that the distribution of earthquakes, with respect to their size, obeys the classic Gutenberg-Richter relation

$$\log N(m) = a - b \cdot (m - m_{\min}), \tag{7}$$

where $N(m)$ is the number of earthquakes of $m \geq m_{\min}$, occurring within a specified period of time, and a and b are parameters.

Aki (1965) found that equation (7) implied a singly truncated exponential distribution of the form

$$\begin{aligned} F_M(m) &= P(M \leq m) \\ &= 1 - e^{-\beta(m - m_{\min})}, \end{aligned} \tag{8}$$

where $\beta = b\ln(10)$.

The earthquake occurrences over time in the given area are assumed to satisfy a Poisson process (1) having an unknown mean seismic activity rate λ.

The disregard of temporal and spatial variations of the parameters λ and b can lead to biased estimates of seismic hazard. An explicit assumption behind most hazard assessment procedures is that parameters λ and b and remain constant in time. However, examination of most earthquake catalogues indicates that there are temporal changes of the mean seismic activity rate λ as well as of the parameter b. For some seismic areas, the b-value has been reported to change (decrease/increase) its value before large earthquakes. Usually, such changes are explained by the state of stress; the higher the stress, the lower the b-value. Other theories connect the b-value with the homogeneity of the rock: the more heterogeneous the rock, the higher the b-value. Finally, some scientists connect the fluctuation of the b -value with the seismicity pattern and believe that the b-value is controlled by the buckling of the stratum. Whatever the mechanism, the phenomenon of space-time b-value fluctuation is indubitable and well-known. A wide range of international opinions concerning changes of patterns in seismicity, together with an extensive reference list, are found in a monograph by Simpson and Richards (1981) and in two special issues of *Pure and Applied Geophysics*, (Seismicity Patterns …, 1999; Microscopic and Macroscopic …, 2000). Treating both parameters λ and b as random variables modelled by respective gamma distributions, allows for appropriately accounting for the statistical uncertainty in these important parameters. In practice, the adoption of the gamma distribution does not really introduce much limitation, since the gamma distribution can fit a large variety of shapes. Combining the Poisson distribution (1) together with the gamma distribution (2) with parameters p_λ and q_λ, the probability related to a certain number of earthquakes, n, per unit time t, for randomly varying seismicity is obtained

$$\begin{aligned} P(n|t) &= \int_0^\infty p(n|\lambda_A, t) f(\lambda_A) d\lambda_A \\ &= \frac{\Gamma(n+q_\lambda)}{n!\Gamma(q_\lambda)} \left(\frac{p_\lambda}{t+p_\lambda}\right)^{q_\lambda} \left(\frac{t}{t+p_\lambda}\right)^n, \end{aligned} \tag{9}$$

where $p_\lambda = \overline{\lambda} / \sigma_\lambda^{\,2}$, $q_\lambda = \overline{\lambda}^2 / \sigma_\lambda^{\,2}$ and Γ(·) is the Gamma function (3). Parameter $\overline{\lambda}$ denotes the mean value of activity rate λ.

Similarly, combining the exponential distribution (8) with the gamma distribution for β with parameters p_β and q_β, and normalizing (e.g. Campbell, 1982) upon introducing an upper limit $m_{\max}$ for the distribution of earthquake magnitudes, the CDF of earthquake magnitudes is obtained

$$F_M\left(m \middle| m_{\min}\right) = C_\beta \left[1 - \left(\frac{p_\beta}{p_\beta + m - m_{\min}} \right)^{q_\beta} \right], \tag{10}$$

where $p_\beta = \overline{\beta} / \sigma_\beta^{\,2}$ and $q_\beta = \overline{\beta}^2 / \sigma_\beta^{\,2}$. The symbol $\overline{\beta}$ denotes the mean value of parameter β, σ_β denotes the standard deviation of β and the normalizing coefficient C_β is given by

$$C_\beta = \left[1 - \left(\frac{p_\beta}{p_\beta + m_{\max} - m_{\min}} \right)^{q_\beta} \right]^{-1}, \tag{11}$$

Noting that $q_\lambda = \overline{\lambda} \cdot p_\lambda$ and $q_\beta = \overline{\beta} \cdot p_\beta$, equations (9) and (10) may alternatively be written respectively as

$$P\left(n \middle| t\right) = \frac{\Gamma\left(n + q_\lambda\right)}{n!\,\Gamma\left(q_\lambda\right)} \left(\frac{q_\lambda}{\overline{\lambda}_A t + q_\lambda} \right)^{q_\lambda} \left(\frac{\overline{\lambda}_A t}{\overline{\lambda}_A t + q_\lambda} \right)^{n}, \tag{12}$$

and

$$F_M\left(m \middle| m_{\min}\right) = C_\beta \left[1 - \left(\frac{q_\beta}{q_\beta + \overline{\beta}\left(m - m_{\min}\right)} \right)^{q_\beta} \right], \tag{13}$$

with

$$C_\beta = \left[1 - \left(\frac{q_\beta}{q_\beta + \beta(m_{\max} - m_{\min})} \right)^{q_\beta} \right]^{-1}, \tag{14}$$

Note that $q_\beta = \left(COV_\beta^{-1}\right)^2$ and $q_\lambda = \left(COV_\lambda^{-1}\right)^2$. Upon specification of the COV, the parameters $\bar{\lambda}$ and $\bar{\beta}$, referred to as hyper-parameters of the respective distributions are estimated on the basis of observed data by applying the maximum likelihood procedure.

2.3.1 Extreme magnitude distribution as applied to prehistoric (paleo) and historic events

The likelihood function of desired seismicity parameters $\boldsymbol{\theta} = (\bar{\lambda}, \bar{\beta})$ is built based on the prehistoric (paleo) and historic parts of the catalogue containing the strongest events only. In this section the details of the likelihood function based on historic earthquakes will be discussed, since except for a few details, the likelihood function based on prehistoric events is built in a similar manner.

By the Theorem of the Total Probability (e.g. Cramér, 1961), the probability that in time interval t either no earthquake occurs, or all occurring earthquakes have magnitude not exceeding m, may be expressed as (Epstein and Lomnitz, 1966; Gan and Tung, 1983; Gibowicz and Kijko, 1994)

$$F_M^{\max}(m \mid m_0, t) = \sum_{i=0}^{\infty} P(i \mid t)\left[F_M(m \mid m_0)\right]^i, \tag{15}$$

Relation (15) can be expressed in a much more simpler form (e.g. Campbell, 1982), which may be written as

$$F_M^{\max}\left(m \,|\, m_0, t\right) = \left[\frac{q_\lambda}{q_\lambda + \overline{\lambda}_0\, t\left[1 - F_M\left(m \,|\, m_0\right)\right]}\right]^{q_\lambda}, \tag{16}$$

In relations (15) and (16), m_0 is the threshold magnitude for the prehistoric or historic part of the catalogue ($m_0 \geq m_{\min}$). Magnitude $m_{\min}$ is the 'total' threshold magnitude and has a rather formal character. The only restriction on the choice of its value is that $m_{\min}$ may not exceed the threshold magnitude of any part - prehistoric, historic or complete - of the catalogue.

It follows from relation (16) that the probability density function (PDF) of the largest earthquake magnitudes m within a period t is

$$f_M^{\max}(m \,|\, m_0, t) = \frac{\overline{\lambda}_0\, t q_\lambda f_M(m \,|\, m_0) F_M^{\max}(m \,|\, m_0, t)}{q_\lambda + \overline{\lambda}_0\, t[1 - F_M(m \,|\, m_0)]}, \tag{17}$$

$\overline{\lambda}_0$ represents the mean of the distribution of the mean activity rate for earthquakes with magnitudes not less than m_0, and is given by

$$\overline{\lambda}_0 = \overline{\lambda}_A\left[1 - F_M\left(m \,|\, m_0\right)\right], \tag{18}$$

where $\overline{\lambda}_A$, as defined above, is the mean of the distribution of the mean activity rate corresponding to magnitude value $m_{\min}$. $f_M\left(m | m_0\right)$ is the PDF of earthquake magnitude. Based on (13) and the definition of the probability density function, it takes the following form:

$$f_M\left(m\right) = C_\beta\, \overline{\beta}\left(\frac{q_\beta}{q_\beta + \overline{\beta}\left(m - m_0\right)}\right)^{q_\beta + 1}, \tag{19}$$

After introducing the PDF (17) of the largest earthquake magnitude m within a period t, the likelihood function of unknown parameters $\boldsymbol{\theta}$ becomes:

$$L_0\left(\boldsymbol{\theta} \,|\, \boldsymbol{m}_0, \boldsymbol{t}_0, \boldsymbol{cov}\right) = \prod_{i=1}^{n_0} f_M^{\max}\left(m_{0i} \,|\, m_0, t_i\right) , \tag{20}$$

In order to build the likelihood function (20), three kinds of input data are required: $\boldsymbol{m}_0$, $\boldsymbol{t}$, and $\boldsymbol{cov}$, where $\boldsymbol{m}_0$ is vector of the largest magnitudes, $\boldsymbol{t}$ denotes vector of the time intervals within which the largest events occurred, and vector $\boldsymbol{cov} = \left(\mathrm{cov}_\lambda, \mathrm{cov}_\beta\right)$, consists of the coefficients of variation (amount of dispersion (uncertainty relative to the mean) of the unknown parameters $\boldsymbol{\theta} = (\bar{\lambda}, \bar{\beta})$.

2.3.2 Combination of extreme and complete seismic catalogues with different levels of completeness

If it is assumed that the third, complete part of the catalogue can be divided into s sub-catalogues (Kijko and Sellevoll, 1992), each of them has a span T_i and is complete starting from the known magnitude $m_{\min}^{(i)}$. For each sub-catalogue i, $\boldsymbol{m}_i$ is used to denote n_i earthquake magnitudes m_{ij}, where $m_{ij} \geq m_{\min}^{(i)}, i = 1,\ldots,s$ and $j = 1,\ldots,n_i$. Let $L_i\left(\boldsymbol{\theta} | \boldsymbol{m}_i\right)$ denote the likelihood function of the unknown $\boldsymbol{\theta} = (\bar{\lambda}, \bar{\beta})$, based on the i-th complete sub-catalogue. If the size of seismic events is independent of their number, the likelihood function $L_i\left(\boldsymbol{\theta} | \boldsymbol{m}_i\right)$ is the product of two functions, $L_i\left(\bar{\lambda} | \mathbf{m}_i\right)$ and $L_i\left(\bar{\beta} | \boldsymbol{m}_i\right)$.

The assumption that the number of earthquakes per unit time is distributed according to (12) means that $L_i\left(\bar{\lambda} \,| \mathbf{m}_i\right)$ has the following form:

$$L_i\left(\bar{\lambda} | \mathbf{m}_i\right) = const \cdot \left(\bar{\lambda}^{(i)} t + q_\lambda\right)^{-q_\lambda} \left(\frac{\bar{\lambda}^{(i)} t}{\bar{\lambda}^{(i)} t + q_\lambda}\right)^{n_i} , \tag{21}$$

where *const* does not depend on $\bar{\lambda}$ and $\bar{\lambda}^{(i)}$ is the mean activity rate corresponding to the threshold magnitude $m_{\min}^{(i)}$ and is given by,

$$\bar{\lambda}^{i} = \bar{\lambda}\ \left[1 - F_M\left(m_{\min}^{(i)} \mid m_{\min}\right)\right], \tag{22}$$

Following the definition of the likelihood function based on a set of independent observations, and (19), $L_i(\beta|\boldsymbol{m}_i)$ takes the form

$$L_i(\bar{\beta}|\boldsymbol{m}_i) = \left[C_\beta\ \bar{\beta}\right]^{n_i} \prod_{j=1}^{n_i} \left[1 + \frac{\bar{\beta}}{q_\beta}\left(m_{ij} - m_{\min}^{(i)}\right)\right]^{-(q_\beta+1)}, \tag{23}$$

Relations (21) and (23) define the likelihood function of the unknown parameters $\boldsymbol{\theta}$ = ($\bar{\lambda}_A$, $\bar{\beta}$) for each complete sub-catalogue.

Finally, $L(\boldsymbol{\theta})$, the joint likelihood function based on all data, i.e. the likelihood function based on the whole catalogue, is calculated as the product of the likelihood functions based on prehistoric, historic and complete data.

The maximum likelihood estimates of the required hazard parameters $\boldsymbol{\theta}$ = ($\bar{\lambda}$, $\bar{\beta}$), are given by the value of $\boldsymbol{\theta}$ which, for a given maximum regional magnitude $m_{\max}$, maximizes the likelihood function $L(\boldsymbol{\theta})$. The maximum of the likelihood function is obtained by solving the system of two equations $\frac{\partial \ell}{\partial \bar{\lambda}_A} = 0$ and $\frac{\partial \ell}{\partial \bar{\beta}} = 0$, where $\ell = \ln\left[L(\boldsymbol{\theta})\right]$.

A variance-covariance matrix $D(\boldsymbol{\theta})$, of the estimated hazard parameters, $\hat{\bar{\lambda}}$ and $\hat{\bar{\beta}}$, is calculated according to the formula (Edwards, 1972):

$$\mathrm{D}(\theta) = -\begin{bmatrix} \dfrac{\partial^2 \ell}{\partial \overline{\lambda}^2} & \dfrac{\partial^2 \ell}{\partial \overline{\lambda}\, \partial \overline{\beta}} \\ \dfrac{\partial^2 \ell}{\partial \overline{\beta} \partial \overline{\lambda}} & \dfrac{\partial^2 \ell}{\partial \overline{\beta}^2} \end{bmatrix}^{-1}, \tag{24}$$

where derivatives are calculated at the point $\overline{\lambda} = \hat{\overline{\lambda}}$ and $\overline{\beta} = \hat{\overline{\beta}}$.

2.4 Estimation of the maximum regional earthquake magnitude $m_{\max}$

Suppose that in the area of concern, within a specified time interval T, there are n main seismic events with magnitudes $m_1, \ldots, m_n$. Each magnitude $m_i \geq m_{\min}$ ($i = 1, \ldots, n$), where $m_{\min}$ is a known threshold of completeness (i.e. all events having magnitude greater than or equal to $m_{\min}$ are recorded). It is further assumed that the seismic event magnitudes are independent, identically distributed, random variables with CDF described by equation (13).

From the condition that compares the largest observed magnitude $m_{\max}^{obs}$ and the maximum expected magnitude during a specified time interval T, the maximum regional magnitude $m_{\max}$ is obtained (Kijko and Graham, 1998; Kijko, 2004)

$$m_{\max} = m_{\max}^{obs} + \frac{\delta^{1/q} \exp\left[n r^q / \left(1 - r^q\right)\right]}{\overline{\beta}} \left[\Gamma\left(-1/q, \delta\, r^q\right) - \Gamma\left(-1/q, \delta\right)\right], \tag{25}$$

where $\delta = nC_\beta$ and $\Gamma(\cdot,\cdot)$ is the complementary incomplete gamma function. The approximate variance of the above estimator is equal to (Kijko, 2004)

$$\sigma_{m_{\max}}^2 \cong \sigma_M^2 + \left\{ \frac{\delta^{1/q} \exp\left[n r^q / \left(1 - r^q\right)\right]}{\overline{\beta}} \left[\Gamma\left(-1/q, \delta\, r^q\right) - \Gamma\left(-1/q, \delta\right)\right] \right\}^2, \tag{26}$$

where σ_M is the standard error in determination of the largest observed magnitude $m_{\max}^{obs}$.

3. The Cornell-McGuire PSHA Methodology

The essence of the PSHA is the calculation of the probability of exceedance of a specified ground motion level at a specified site. The so called, Cornell-McGuire solution of this problem consists of four steps: (e.g. Budnitz *et al.*, 1997; Reiter, 1990):

1. Determination of the possible seismic sources around the site. The sources are typically identified faults, point sources, or area sources, in which it is assumed that the occurrence of earthquakes is spatially uniform. In the territory of Eastern and Southern Africa, like the central and eastern United States or Australia, the main contribution to the seismic hazard comes from the area sources. The seismicity of the area not always correlates well with geological structures recognizable at the surface therefore identification of the geological structures that are responsible for earthquakes are difficult.

2. Determination and assessment of the recurrence parameters for each seismic source. This is typically expressed in terms of three parameters: the mean seismic activity rate λ , b-value of the Gutenberg – Richter frequency magnitude relation and the upper-bound of earthquake magnitude $m_{\max}$.

Selection of the ground motion prediction equation (GMPE), which is most suitable for the region, is crucial. For Eastern and Southern Africa areas, the strong motion records are very limited therefore theoretical models of the ground motion attenuation are used. Since the ground motion attenuation relationship is a major source of uncertainty in the computed PSHA, some codes and recommendations require use of a number of alternative GMPE's (Bernreuter *et al.*, 1989).

3. Computation of the hazard curves. These curves are usually expressed in terms of the mean annual frequency of events with site ground motion level a or more, $\lambda(a)$ or

probability of exceedance, Pr[A>a in time t], vs. a ground motion parameter a, like PGA or a spectral acceleration. By the Theorem of the Total Probability, (Cramér, 1961), the frequency $\lambda(a)$, is defined as (Budnitz, 1997)

$$\lambda(a) = \sum_{i=1}^{n_s} \lambda_i \int_{m_{\min}}^{m_{\max}} \int_{R|M} \Pr[A \geq a \mid M, R] \, f_M(m) \, f_{R|M}(r \mid m) \, dr \, dm \tag{27}$$

in which the subscripts i, (i=1,…n_S), denoting seismic source number are deleted for simplicity. In equation (27), λ is the mean activity rate (per time unit and per seismic area unit) of earthquakes on seismic source i, having magnitudes between m_{min} and m_{max}; m_{min} is the minimum magnitude of engineering significance; m_{max} is the maximum earthquake magnitude assumed to occur on the seismic source; Pr $[A \geq a|M, R]$ denotes the conditional probability that the chosen ground motion level is exceeded for a given magnitude and distance. Standard choice for Pr $[A \geq a|M, R]$ is Gaussian complementary cumulative distribution function, which is based on the assumption that the ground motion parameter a is a lognormal random (aleatory) variable. In equation (27), $f_M(m)$ denotes the PDF of earthquake magnitude. In most engineering applications it is assumed that earthquake magnitudes follow the Gutenberg-Richter relation, which implies that $f_M(m)$ is negative, exponential distribution, with magnitudes between m_{min} and m_{max}. If uncertainty of the earthquake magnitude distribution is taken into account, $f_M(m)$ takes the familiar (Bayesian) form of equation (19). Finally, PDF $f_{R|M}(r \mid m)$ describes the spatial distribution of earthquake occurrence, or, more precisely, the PDF of distance from the earthquake source to the site of interest. In general cases, spatial distribution of the earthquake occurrence can be different for different earthquake magnitudes.

Under the condition that earthquake occurrence in every seismic source is Poisson event, i.e. independent in time and space, the ground motion $A \geq a$ at a site is also a Poisson event. Hence the probability, that a, a specified level of ground motion at a given site, will be exceeded at least once in any time interval t is

Pr[$A > a$ in time t] =

$$1-\exp\left[-\sum_{i=1}^{n_s}\lambda_i\int_{m_{\min}}^{m_{\max}}\int_{R|M}\Pr[A\geq a\,|\,M,R]\,f_M(m)\,f_{R|M}(r\,|\,m)\,dr\,dm\right]. \qquad (28)$$

The equation (28) is fundamental in PSHA. The plot of this equation vs. ground motion parameter *a*, is the hazard curve – the ultimate product of the PSHA assessment.

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Appendix C

Seismic Sources and their Recurrence Parameters

DIFFUSE AREAL (POINT) SEISMIC SOURCES AND THEIR PARAMETERS

Lat	Long	Depth	m_min	Lambda	b	m_max
-34.058	16.500	10.0	4.0	3.688135e-004	0.96	6.32
-33.808	16.500	10.0	4.0	3.698955e-004	0.96	6.32
-30.808	16.500	10.0	4.0	1.060180e-003	0.96	6.20
-30.558	16.500	10.0	4.0	1.062922e-003	0.96	6.20
-30.308	16.500	10.0	4.0	2.131289e-003	0.96	6.20
-30.058	16.500	10.0	4.0	7.962801e-004	0.96	6.20
-34.558	16.750	10.0	4.0	3.667109e-004	0.96	6.33
-34.308	16.750	10.0	4.0	3.677246e-004	0.96	6.32
-34.058	16.750	10.0	4.0	3.688135e-004	0.96	6.32
-33.808	16.750	10.0	4.0	3.698955e-004	0.96	6.32
-33.558	16.750	10.0	4.0	3.709704e-004	0.96	6.32
-33.308	16.750	10.0	4.0	3.720382e-004	0.96	6.32
-31.308	16.750	10.0	4.0	1.054636e-003	0.96	6.20
-31.058	16.750	10.0	4.0	1.057418e-003	0.96	6.20
-30.808	16.750	10.0	4.0	1.060180e-003	0.96	6.20
-30.558	16.750	10.0	4.0	9.320634e-004	0.96	6.20
-30.308	16.750	10.0	4.0	1.530505e-003	0.96	6.20
-30.058	16.750	10.0	4.0	1.534385e-003	0.96	6.20
-34.808	17.000	10.0	4.0	3.656077e-004	0.96	6.33
-34.558	17.000	10.0	4.0	5.815522e-003	0.96	6.32
-34.308	17.000	10.0	4.0	5.832906e-003	0.96	6.32
-34.058	17.000	10.0	4.0	5.850180e-003	0.96	6.32
-33.808	17.000	10.0	4.0	5.867342e-003	0.96	6.32
-33.558	17.000	10.0	4.0	5.884392e-003	0.96	6.32
-33.308	17.000	10.0	4.0	3.720382e-004	0.96	6.32
-33.058	17.000	10.0	4.0	3.730989e-004	0.96	6.32
-31.558	17.000	10.0	4.0	1.047812e-003	0.96	6.34
-31.308	17.000	10.0	4.0	1.054636e-003	0.96	6.20
-31.058	17.000	10.0	4.0	1.057418e-003	0.96	6.20
-30.808	17.000	10.0	4.0	1.060180e-003	0.96	6.20
-30.558	17.000	10.0	4.0	9.079985e-004	0.96	6.20
-30.308	17.000	10.0	4.0	1.178614e-003	1.11	6.20
-30.058	17.000	10.0	4.0	1.342700e-003	1.07	6.20
-29.808	17.000	10.0	4.0	1.456511e-003	1.04	6.20
-34.808	17.250	10.0	4.0	5.798027e-003	0.96	6.32
-34.558	17.250	10.0	4.0	5.815522e-003	0.96	6.32
-34.308	17.250	10.0	4.0	5.832906e-003	0.96	6.32
-34.058	17.250	10.0	4.0	5.850180e-003	0.96	6.32
-33.808	17.250	10.0	4.0	5.867342e-003	0.96	6.32
-33.558	17.250	10.0	4.0	5.404203e-003	0.96	6.32
-33.308	17.250	10.0	4.0	5.901330e-003	0.96	6.32
-33.058	17.250	10.0	4.0	3.730989e-004	0.96	6.32
-31.558	17.250	10.0	4.0	1.048798e-003	0.96	6.30
-31.308	17.250	10.0	4.0	1.050152e-003	0.96	6.36
-31.058	17.250	10.0	4.0	1.057418e-003	0.96	6.20
-30.808	17.250	10.0	4.0	9.056561e-004	0.96	6.20
-30.558	17.250	10.0	4.0	9.079985e-004	0.96	6.20
-30.308	17.250	10.0	4.0	1.449191e-003	1.04	6.20
-30.058	17.250	10.0	4.0	1.452865e-003	1.04	6.20
-29.808	17.250	10.0	4.0	1.571748e-003	1.02	6.20
-34.808	17.500	10.0	4.0	5.798027e-003	0.96	6.32
-34.558	17.500	10.0	4.0	5.815522e-003	0.96	6.32
-34.308	17.500	10.0	4.0	5.832906e-003	0.96	6.32
-34.058	17.500	10.0	4.0	4.987674e-003	0.96	6.32
-33.808	17.500	10.0	4.0	5.031060e-003	0.96	6.32
-33.558	17.500	10.0	4.0	3.800260e-003	1.05	6.32

-33.308	17.500	10.0	4.0	3.258533e-003	1.03	6.32
-33.058	17.500	10.0	4.0	3.586147e-003	1.07	6.32
-32.808	17.500	10.0	4.0	9.071819e-004	0.96	6.32
-31.808	17.500	10.0	4.0	1.045727e-003	0.96	6.31
-31.558	17.500	10.0	4.0	1.048798e-003	0.96	6.30
-31.308	17.500	10.0	4.0	1.050375e-003	0.96	6.35
-31.058	17.500	10.0	4.0	9.272368e-004	0.96	6.20
-30.808	17.500	10.0	4.0	9.056561e-004	0.96	6.20
-30.558	17.500	10.0	4.0	8.067876e-004	1.08	6.20
-30.308	17.500	10.0	4.0	1.578143e-003	1.02	6.20
-30.058	17.500	10.0	4.0	1.692854e-003	1.00	6.20
-29.808	17.500	10.0	4.0	1.697102e-003	1.00	6.20
-29.558	17.500	10.0	4.0	1.760101e-003	1.00	6.20
-35.058	17.750	10.0	4.0	5.780422e-003	0.96	6.32
-34.808	17.750	10.0	4.0	5.798027e-003	0.96	6.32
-34.558	17.750	10.0	4.0	5.815522e-003	0.96	6.32
-34.308	17.750	10.0	4.0	4.972947e-003	0.96	6.32
-34.058	17.750	10.0	4.0	3.459280e-003	1.00	6.32
-33.808	17.750	10.0	4.0	4.416341e-003	0.95	6.32
-33.558	17.750	10.0	4.0	4.881096e-003	0.94	6.32
-33.308	17.750	10.0	4.0	4.895146e-003	0.94	6.32
-33.058	17.750	10.0	4.0	4.668607e-003	0.94	6.32
-32.808	17.750	10.0	4.0	1.158476e-003	1.00	6.32
-32.558	17.750	10.0	4.0	8.201065e-004	0.96	6.32
-31.808	17.750	10.0	4.0	1.045727e-003	0.96	6.31
-31.558	17.750	10.0	4.0	1.048798e-003	0.96	6.30
-31.308	17.750	10.0	4.0	1.050375e-003	0.96	6.35
-31.058	17.750	10.0	4.0	9.972541e-004	0.96	6.36
-30.808	17.750	10.0	4.0	8.047064e-004	1.08	6.20
-30.558	17.750	10.0	4.0	9.088384e-004	1.05	6.20
-30.308	17.750	10.0	4.0	1.162729e-003	0.98	6.20
-30.058	17.750	10.0	4.0	1.914667e-003	0.95	6.20
-29.808	17.750	10.0	4.0	1.919472e-003	0.95	6.20
-29.558	17.750	10.0	4.0	1.760101e-003	1.00	6.20
-35.058	18.000	10.0	4.0	5.780422e-003	0.96	6.32
-34.808	18.000	10.0	4.0	5.798027e-003	0.96	6.32
-34.558	18.000	10.0	4.0	4.958126e-003	0.96	6.32
-34.308	18.000	10.0	4.0	3.449066e-003	1.00	6.32
-34.058	18.000	10.0	4.0	5.278962e-003	0.91	6.32
-33.808	18.000	10.0	4.0	5.294449e-003	0.91	6.32
-33.558	18.000	10.0	4.0	5.309834e-003	0.91	6.32
-33.308	18.000	10.0	4.0	5.582161e-003	0.89	6.32
-33.058	18.000	10.0	4.0	5.598077e-003	0.89	6.32
-32.808	18.000	10.0	4.0	5.389025e-003	0.91	6.32
-32.558	18.000	10.0	4.0	1.604218e-003	1.01	6.31
-32.308	18.000	10.0	4.0	8.225244e-004	0.96	6.31
-31.808	18.000	10.0	4.0	1.045727e-003	0.96	6.31
-31.558	18.000	10.0	4.0	1.048798e-003	0.96	6.30
-31.308	18.000	10.0	4.0	9.217909e-004	0.96	6.34
-31.058	18.000	10.0	4.0	9.974029e-004	0.96	6.35
-30.808	18.000	10.0	4.0	1.063265e-003	0.99	6.20
-30.558	18.000	10.0	4.0	1.066015e-003	0.99	6.20
-30.308	18.000	10.0	4.0	1.162729e-003	0.98	6.20
-30.058	18.000	10.0	4.0	1.970990e-003	0.95	6.20
-29.808	18.000	10.0	4.0	2.163105e-003	0.92	6.20
-29.558	18.000	10.0	4.0	2.218295e-003	0.92	6.20
-35.058	18.250	10.0	4.0	5.780422e-003	0.96	6.32
-34.808	18.250	10.0	4.0	5.798027e-003	0.96	6.32
-34.558	18.250	10.0	4.0	4.958126e-003	0.96	6.32
-34.308	18.250	10.0	4.0	5.181776e-003	0.91	6.32
-34.058	18.250	10.0	4.0	5.278962e-003	0.91	6.32
-33.808	18.250	10.0	4.0	5.693527e-003	0.89	6.32
-33.558	18.250	10.0	4.0	5.710072e-003	0.89	6.32
-33.308	18.250	10.0	4.0	5.726508e-003	0.89	6.32
-33.058	18.250	10.0	4.0	5.742836e-003	0.89	6.32
-32.808	18.250	10.0	4.0	5.759054e-003	0.89	6.32
-32.558	18.250	10.0	4.0	3.418271e-003	0.95	6.31
-32.308	18.250	10.0	4.0	1.606025e-003	1.01	6.31
-32.058	18.250	10.0	4.0	1.042894e-003	0.96	6.31
-31.808	18.250	10.0	4.0	1.045727e-003	0.96	6.31
-31.558	18.250	10.0	4.0	1.048541e-003	0.96	6.31

-31.308	18.250	10.0	4.0	9.217909e-004	0.96	6.34
-31.058	18.250	10.0	4.0	8.436289e-004	0.96	6.35
-30.808	18.250	10.0	4.0	1.060038e-003	0.99	6.38
-30.558	18.250	10.0	4.0	1.034447e-003	0.97	6.20
-30.308	18.250	10.0	4.0	1.266526e-003	0.93	6.20
-30.058	18.250	10.0	4.0	1.269737e-003	0.93	6.20
-29.808	18.250	10.0	4.0	1.901726e-003	0.91	6.20
-29.558	18.250	10.0	4.0	1.775994e-003	0.92	6.20
-29.308	18.250	10.0	4.0	2.223750e-003	0.92	6.20
-35.058	18.500	10.0	4.0	5.780422e-003	0.96	6.32
-34.808	18.500	10.0	4.0	4.943210e-003	0.96	6.32
-34.558	18.500	10.0	4.0	4.284535e-003	0.95	6.32
-34.308	18.500	10.0	4.0	5.263376e-003	0.91	6.32
-34.058	18.500	10.0	4.0	5.676873e-003	0.89	6.32
-33.808	18.500	10.0	4.0	5.693527e-003	0.89	6.32
-33.558	18.500	10.0	4.0	5.710072e-003	0.89	6.32
-33.308	18.500	10.0	4.0	5.726508e-003	0.89	6.32
-33.058	18.500	10.0	4.0	5.742836e-003	0.89	6.32
-32.808	18.500	10.0	4.0	5.759054e-003	0.89	6.32
-32.558	18.500	10.0	4.0	3.902498e-003	0.93	6.31
-32.308	18.500	10.0	4.0	3.110098e-003	0.96	6.31
-32.058	18.500	10.0	4.0	8.908455e-004	0.96	6.31
-31.808	18.500	10.0	4.0	1.045727e-003	0.96	6.31
-31.558	18.500	10.0	4.0	1.048541e-003	0.96	6.31
-31.308	18.500	10.0	4.0	9.217909e-004	0.96	6.34
-31.058	18.500	10.0	4.0	8.436289e-004	0.96	6.35
-30.808	18.500	10.0	4.0	1.072004e-003	0.97	6.36
-30.558	18.500	10.0	4.0	1.263291e-003	0.93	6.20
-30.308	18.500	10.0	4.0	1.266526e-003	0.93	6.20
-30.058	18.500	10.0	4.0	1.269737e-003	0.93	6.20
-29.808	18.500	10.0	4.0	1.388715e-003	0.92	6.20
-29.558	18.500	10.0	4.0	1.440054e-003	0.92	6.20
-29.308	18.500	10.0	4.0	2.114583e-003	0.91	6.20
-35.058	18.750	10.0	4.0	5.780422e-003	0.96	6.32
-34.808	18.750	10.0	4.0	4.943210e-003	0.96	6.32
-34.558	18.750	10.0	4.0	5.040267e-003	0.91	6.32
-34.308	18.750	10.0	4.0	5.403410e-003	0.91	6.32
-34.058	18.750	10.0	4.0	5.676873e-003	0.89	6.32
-33.808	18.750	10.0	4.0	5.693527e-003	0.89	6.32
-33.558	18.750	10.0	4.0	5.710072e-003	0.89	6.32
-33.308	18.750	10.0	4.0	5.726508e-003	0.89	6.32
-33.058	18.750	10.0	4.0	5.742836e-003	0.89	6.32
-32.808	18.750	10.0	4.0	5.759054e-003	0.89	6.32
-32.558	18.750	10.0	4.0	3.902498e-003	0.93	6.31
-32.308	18.750	10.0	4.0	3.705801e-003	0.95	6.31
-32.058	18.750	10.0	4.0	1.087739e-003	1.11	6.31
-31.558	18.750	10.0	4.0	1.048541e-003	0.96	6.31
-31.308	18.750	10.0	4.0	8.557335e-004	0.96	6.35
-31.058	18.750	10.0	4.0	6.497890e-004	1.08	6.34
-30.808	18.750	10.0	4.0	1.139910e-003	0.94	6.34
-30.558	18.750	10.0	4.0	1.263291e-003	0.93	6.20
-30.308	18.750	10.0	4.0	1.266526e-003	0.93	6.20
-30.058	18.750	10.0	4.0	1.385238e-003	0.92	6.20
-29.808	18.750	10.0	4.0	1.528742e-003	0.92	6.20
-29.558	18.750	10.0	4.0	1.532540e-003	0.92	6.20
-29.308	18.750	10.0	4.0	1.846665e-003	0.93	6.20
-35.058	19.000	10.0	4.0	5.780422e-003	0.96	6.32
-34.808	19.000	10.0	4.0	4.987516e-003	0.96	6.32
-34.558	19.000	10.0	4.0	5.268268e-003	0.91	6.32
-34.308	19.000	10.0	4.0	5.660112e-003	0.89	6.32
-34.058	19.000	10.0	4.0	5.676873e-003	0.89	6.32
-33.808	19.000	10.0	4.0	5.693527e-003	0.89	6.32
-33.558	19.000	10.0	4.0	5.710072e-003	0.89	6.32
-33.308	19.000	10.0	4.0	6.585846e-003	0.90	6.32
-33.058	19.000	10.0	4.0	6.604624e-003	0.90	6.32
-32.808	19.000	10.0	4.0	6.254455e-003	0.93	6.32
-32.558	19.000	10.0	4.0	5.456233e-003	0.93	6.31
-32.308	19.000	10.0	4.0	3.913309e-003	0.93	6.31
-32.058	19.000	10.0	4.0	2.036485e-003	1.03	6.31
-31.808	19.000	10.0	4.0	8.932659e-004	0.96	6.31
-31.558	19.000	10.0	4.0	1.048798e-003	0.96	6.30

-31.308	19.000	10.0	4.0	8.558908e-004	0.96	6.34
-31.058	19.000	10.0	4.0	6.497890e-004	1.08	6.34
-30.808	19.000	10.0	4.0	1.071372e-003	0.95	6.34
-30.558	19.000	10.0	4.0	1.144596e-003	0.94	6.20
-30.308	19.000	10.0	4.0	1.381736e-003	0.92	6.20
-30.058	19.000	10.0	4.0	1.524915e-003	0.92	6.20
-29.808	19.000	10.0	4.0	1.528742e-003	0.92	6.20
-29.558	19.000	10.0	4.0	1.532540e-003	0.92	6.20
-29.308	19.000	10.0	4.0	1.582193e-003	0.91	6.20
-35.058	19.250	10.0	4.0	6.051051e-003	0.96	6.32
-34.808	19.250	10.0	4.0	4.987516e-003	0.96	6.32
-34.558	19.250	10.0	4.0	5.268268e-003	0.91	6.32
-34.308	19.250	10.0	4.0	5.660112e-003	0.89	6.32
-34.058	19.250	10.0	4.0	5.676873e-003	0.89	6.32
-33.808	19.250	10.0	4.0	6.547916e-003	0.90	6.32
-33.558	19.250	10.0	4.0	6.566944e-003	0.90	6.32
-33.308	19.250	10.0	4.0	6.585846e-003	0.90	6.32
-33.058	19.250	10.0	4.0	6.604624e-003	0.90	6.32
-32.808	19.250	10.0	4.0	5.753532e-003	0.93	6.32
-32.558	19.250	10.0	4.0	5.775455e-003	0.93	6.31
-32.308	19.250	10.0	4.0	5.791454e-003	0.93	6.31
-32.058	19.250	10.0	4.0	2.036485e-003	1.03	6.31
-31.808	19.250	10.0	4.0	5.730253e-004	0.96	6.30
-31.308	19.250	10.0	4.0	7.278946e-004	0.96	6.35
-31.058	19.250	10.0	4.0	7.133338e-004	1.06	6.35
-30.808	19.250	10.0	4.0	8.965865e-004	0.99	6.34
-30.558	19.250	10.0	4.0	1.076925e-003	0.95	6.20
-30.308	19.250	10.0	4.0	1.430933e-003	0.92	6.20
-30.058	19.250	10.0	4.0	1.526342e-003	0.90	6.20
-29.808	19.250	10.0	4.0	1.530173e-003	0.90	6.20
-29.558	19.250	10.0	4.0	2.045603e-003	0.90	6.20
-29.308	19.250	10.0	4.0	1.810625e-003	0.90	6.20
-35.058	19.500	10.0	4.0	6.051051e-003	0.96	6.32
-34.808	19.500	10.0	4.0	5.618441e-003	0.96	6.32
-34.558	19.500	10.0	4.0	5.268268e-003	0.91	6.32
-34.308	19.500	10.0	4.0	5.660112e-003	0.89	6.32
-34.058	19.500	10.0	4.0	5.868126e-003	0.89	6.32
-33.808	19.500	10.0	4.0	6.709080e-003	0.90	6.32
-33.558	19.500	10.0	4.0	6.728576e-003	0.90	6.32
-33.308	19.500	10.0	4.0	6.747944e-003	0.90	6.32
-33.058	19.500	10.0	4.0	6.035076e-003	0.93	6.32
-32.808	19.500	10.0	4.0	5.753532e-003	0.93	6.32
-32.558	19.500	10.0	4.0	5.775455e-003	0.93	6.31
-32.308	19.500	10.0	4.0	5.667826e-003	0.94	6.31
-32.058	19.500	10.0	4.0	4.549306e-003	1.01	6.30
-31.808	19.500	10.0	4.0	5.730253e-004	0.96	6.30
-31.308	19.500	10.0	4.0	5.470165e-004	0.96	6.35
-31.058	19.500	10.0	4.0	5.491815e-004	1.07	6.35
-30.808	19.500	10.0	4.0	9.385523e-004	0.97	6.35
-30.558	19.500	10.0	4.0	1.053892e-003	0.93	6.20
-30.308	19.500	10.0	4.0	1.431258e-003	0.89	6.20
-30.058	19.500	10.0	4.0	1.709761e-003	0.89	6.20
-29.808	19.500	10.0	4.0	2.040664e-003	0.88	6.20
-29.558	19.500	10.0	4.0	1.990646e-003	0.89	6.20
-29.308	19.500	10.0	4.0	2.003337e-003	0.89	6.20
-34.808	19.750	10.0	4.0	5.568096e-003	0.96	6.32
-34.558	19.750	10.0	4.0	4.755885e-003	0.95	6.32
-34.308	19.750	10.0	4.0	5.481840e-003	0.92	6.32
-34.058	19.750	10.0	4.0	6.318713e-003	0.92	6.32
-33.808	19.750	10.0	4.0	6.337250e-003	0.92	6.32
-33.558	19.750	10.0	4.0	6.355666e-003	0.92	6.32
-33.308	19.750	10.0	4.0	6.017918e-003	0.93	6.32
-33.058	19.750	10.0	4.0	6.035076e-003	0.93	6.32
-32.808	19.750	10.0	4.0	6.052120e-003	0.93	6.32
-32.558	19.750	10.0	4.0	5.775455e-003	0.93	6.31
-32.308	19.750	10.0	4.0	5.382828e-003	0.96	6.30
-32.058	19.750	10.0	4.0	5.978639e-003	1.06	6.30
-31.808	19.750	10.0	4.0	3.265330e-003	1.12	6.30
-31.308	19.750	10.0	4.0	5.091987e-004	0.96	6.35
-31.058	19.750	10.0	4.0	5.491815e-004	1.07	6.35
-30.808	19.750	10.0	4.0	6.950169e-004	1.01	6.35

-30.558	19.750	10.0	4.0	1.115314e-003	0.94	6.20
-30.308	19.750	10.0	4.0	1.326255e-003	0.93	6.20
-30.058	19.750	10.0	4.0	1.604236e-003	0.90	6.20
-29.808	19.750	10.0	4.0	1.841391e-003	0.89	6.20
-29.558	19.750	10.0	4.0	1.949058e-003	0.89	6.20
-34.808	20.000	10.0	4.0	5.538363e-004	0.96	6.32
-34.558	20.000	10.0	4.0	4.112030e-003	1.01	6.32
-34.308	20.000	10.0	4.0	5.546235e-003	0.91	6.32
-34.058	20.000	10.0	4.0	6.318713e-003	0.92	6.32
-33.808	20.000	10.0	4.0	5.983258e-003	0.93	6.32
-33.558	20.000	10.0	4.0	6.000645e-003	0.93	6.32
-33.308	20.000	10.0	4.0	6.017918e-003	0.93	6.32
-33.058	20.000	10.0	4.0	6.035076e-003	0.93	6.32
-32.808	20.000	10.0	4.0	6.052120e-003	0.93	6.32
-32.558	20.000	10.0	4.0	5.953603e-003	0.93	6.31
-32.308	20.000	10.0	4.0	5.382828e-003	0.96	6.30
-32.058	20.000	10.0	4.0	5.310038e-003	1.07	6.30
-31.808	20.000	10.0	4.0	3.995992e-003	1.09	6.30
-31.308	20.000	10.0	4.0	6.200387e-004	0.96	6.35
-31.058	20.000	10.0	4.0	5.105421e-004	0.96	6.35
-30.808	20.000	10.0	4.0	8.849507e-004	0.96	6.35
-30.558	20.000	10.0	4.0	1.032731e-003	0.95	6.20
-30.308	20.000	10.0	4.0	1.164856e-003	0.94	6.20
-30.058	20.000	10.0	4.0	1.652457e-003	0.93	6.20
-29.808	20.000	10.0	4.0	1.544836e-003	0.92	6.20
-29.558	20.000	10.0	4.0	1.838735e-003	0.90	6.20
-34.558	20.250	10.0	4.0	2.238334e-003	0.96	6.32
-34.308	20.250	10.0	4.0	4.208344e-003	0.96	6.32
-34.058	20.250	10.0	4.0	5.715316e-003	0.93	6.32
-33.808	20.250	10.0	4.0	5.983258e-003	0.93	6.32
-33.558	20.250	10.0	4.0	6.000645e-003	0.93	6.32
-33.308	20.250	10.0	4.0	6.017918e-003	0.93	6.32
-33.058	20.250	10.0	4.0	6.035076e-003	0.93	6.32
-32.808	20.250	10.0	4.0	5.930975e-003	0.93	6.32
-32.558	20.250	10.0	4.0	5.659177e-003	0.95	6.30
-32.308	20.250	10.0	4.0	8.658698e-003	1.00	6.30
-32.058	20.250	10.0	4.0	3.985165e-003	1.09	6.30
-31.808	20.250	10.0	4.0	5.183998e-003	1.14	6.34
-31.558	20.250	10.0	4.0	3.795652e-004	0.96	6.35
-31.308	20.250	10.0	4.0	3.805765e-004	0.96	6.35
-31.058	20.250	10.0	4.0	5.105421e-004	0.96	6.35
-30.808	20.250	10.0	4.0	9.740130e-004	0.98	6.36
-30.558	20.250	10.0	4.0	1.512885e-003	0.91	6.20
-30.308	20.250	10.0	4.0	1.649869e-003	0.91	6.20
-30.058	20.250	10.0	4.0	1.960040e-003	0.90	6.20
-29.808	20.250	10.0	4.0	1.964959e-003	0.90	6.20
-29.558	20.250	10.0	4.0	1.859399e-003	0.91	6.20
-34.558	20.500	10.0	4.0	8.655775e-004	0.96	6.32
-34.308	20.500	10.0	4.0	7.274064e-003	1.04	6.32
-34.058	20.500	10.0	4.0	1.119532e-002	0.95	6.32
-33.808	20.500	10.0	4.0	5.614061e-003	0.93	6.32
-33.558	20.500	10.0	4.0	5.880531e-003	0.93	6.32
-33.308	20.500	10.0	4.0	5.897458e-003	0.93	6.32
-33.058	20.500	10.0	4.0	5.615851e-003	0.95	6.32
-32.808	20.500	10.0	4.0	6.245246e-003	0.96	6.32
-32.558	20.500	10.0	4.0	1.006942e-002	0.97	6.30
-32.308	20.500	10.0	4.0	5.395966e-003	1.06	6.30
-32.058	20.500	10.0	4.0	3.375875e-003	1.08	6.30
-31.808	20.500	10.0	4.0	4.086139e-003	1.12	6.35
-31.558	20.500	10.0	4.0	3.162321e-004	0.96	6.35
-31.308	20.500	10.0	4.0	3.805765e-004	0.96	6.35
-31.058	20.500	10.0	4.0	8.354628e-004	0.96	6.35
-30.808	20.500	10.0	4.0	1.025129e-003	0.98	6.20
-30.558	20.500	10.0	4.0	1.401490e-003	0.93	6.20
-30.308	20.500	10.0	4.0	1.536511e-003	0.92	6.20
-30.058	20.500	10.0	4.0	1.960040e-003	0.90	6.20
-29.808	20.500	10.0	4.0	1.964959e-003	0.90	6.20
-34.558	20.750	10.0	4.0	1.013234e-003	0.96	6.32
-34.308	20.750	10.0	4.0	1.879875e-003	0.96	6.32
-34.058	20.750	10.0	4.0	6.134074e-003	1.02	6.32
-33.808	20.750	10.0	4.0	9.824471e-003	0.97	6.32

-33.558	20.750	10.0	4.0	9.600870e-003	0.95	6.32
-33.308	20.750	10.0	4.0	1.129321e-002	0.95	6.32
-33.058	20.750	10.0	4.0	1.195810e-002	0.97	6.32
-32.808	20.750	10.0	4.0	8.801326e-003	1.00	6.32
-32.558	20.750	10.0	4.0	4.489438e-003	1.05	6.31
-32.308	20.750	10.0	4.0	3.940669e-003	1.06	6.31
-32.058	20.750	10.0	4.0	4.075067e-003	1.12	6.35
-31.808	20.750	10.0	4.0	4.086139e-003	1.12	6.35
-31.558	20.750	10.0	4.0	3.162321e-004	0.96	6.35
-31.308	20.750	10.0	4.0	3.170747e-004	0.96	6.35
-31.058	20.750	10.0	4.0	9.617194e-004	0.96	6.35
-30.808	20.750	10.0	4.0	1.100229e-003	1.04	6.20
-30.558	20.750	10.0	4.0	1.103075e-003	1.04	6.20
-30.308	20.750	10.0	4.0	1.536511e-003	0.92	6.20
-30.058	20.750	10.0	4.0	1.829589e-003	0.92	6.20
-29.808	20.750	10.0	4.0	1.900727e-003	0.92	6.20
-34.558	21.000	10.0	4.0	8.908249e-004	0.96	6.32
-34.308	21.000	10.0	4.0	1.655710e-003	0.96	6.32
-34.058	21.000	10.0	4.0	5.828112e-003	1.05	6.32
-33.808	21.000	10.0	4.0	4.664418e-003	1.03	6.32
-33.558	21.000	10.0	4.0	5.310288e-003	1.01	6.32
-33.308	21.000	10.0	4.0	5.555254e-003	1.00	6.32
-33.058	21.000	10.0	4.0	5.808353e-003	1.03	6.32
-32.808	21.000	10.0	4.0	4.476916e-003	1.05	6.31
-32.558	21.000	10.0	4.0	4.818448e-003	1.10	6.31
-32.308	21.000	10.0	4.0	4.822199e-003	1.10	6.35
-32.058	21.000	10.0	4.0	4.075067e-003	1.12	6.35
-31.808	21.000	10.0	4.0	4.086139e-003	1.12	6.35
-31.558	21.000	10.0	4.0	3.162321e-004	0.96	6.35
-31.308	21.000	10.0	4.0	6.971008e-004	0.96	6.35
-31.058	21.000	10.0	4.0	9.593698e-004	0.96	6.20
-30.808	21.000	10.0	4.0	9.587134e-004	1.08	6.20
-30.558	21.000	10.0	4.0	1.103075e-003	1.04	6.20
-30.308	21.000	10.0	4.0	1.456804e-003	1.01	6.20
-30.058	21.000	10.0	4.0	1.876606e-003	0.99	6.20
-34.308	21.250	10.0	4.0	8.934878e-004	0.96	6.32
-34.058	21.250	10.0	4.0	5.089516e-003	1.06	6.32
-33.808	21.250	10.0	4.0	5.104446e-003	1.06	6.32
-33.558	21.250	10.0	4.0	5.862195e-003	1.05	6.32
-33.308	21.250	10.0	4.0	5.879069e-003	1.05	6.32
-33.058	21.250	10.0	4.0	5.895832e-003	1.05	6.32
-32.808	21.250	10.0	4.0	4.805008e-003	1.10	6.31
-32.558	21.250	10.0	4.0	4.803597e-003	1.10	6.36
-32.308	21.250	10.0	4.0	4.816904e-003	1.10	6.36
-32.058	21.250	10.0	4.0	4.075067e-003	1.12	6.35
-31.808	21.250	10.0	4.0	3.322341e-003	1.14	6.35
-31.558	21.250	10.0	4.0	3.162321e-004	0.96	6.35
-31.308	21.250	10.0	4.0	6.971008e-004	0.96	6.35
-31.058	21.250	10.0	4.0	6.971628e-004	0.96	6.20
-30.808	21.250	10.0	4.0	1.063926e-003	1.07	6.20
-30.558	21.250	10.0	4.0	1.549823e-003	1.07	6.20
-30.308	21.250	10.0	4.0	1.111976e-003	1.04	6.20
-30.058	21.250	10.0	4.0	1.114795e-003	1.04	6.20
-34.308	21.500	10.0	4.0	8.934878e-004	0.96	6.32
-34.058	21.500	10.0	4.0	1.660613e-003	0.96	6.32
-33.808	21.500	10.0	4.0	5.104446e-003	1.06	6.32
-33.558	21.500	10.0	4.0	5.119279e-003	1.06	6.32
-33.308	21.500	10.0	4.0	5.134015e-003	1.06	6.32
-33.058	21.500	10.0	4.0	5.261921e-003	1.06	6.38
-32.808	21.500	10.0	4.0	4.790198e-003	1.10	6.36
-32.558	21.500	10.0	4.0	4.803597e-003	1.10	6.36
-32.308	21.500	10.0	4.0	4.816904e-003	1.10	6.36
-32.058	21.500	10.0	4.0	4.073927e-003	1.12	6.36
-31.808	21.500	10.0	4.0	2.702847e-004	0.96	6.35
-31.558	21.500	10.0	4.0	3.162321e-004	0.96	6.35
-31.308	21.500	10.0	4.0	6.953284e-004	0.96	6.20
-31.058	21.500	10.0	4.0	7.835372e-004	0.96	6.20
-30.808	21.500	10.0	4.0	7.916896e-004	1.10	6.20
-30.558	21.500	10.0	4.0	1.165875e-003	1.05	6.20
-30.308	21.500	10.0	4.0	1.553792e-003	1.07	6.20
-34.058	21.750	10.0	4.0	8.953172e-004	0.96	6.38

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  -33.808     21.750    10.0      4.0    5.088207e-003    1.06     6.38
  -33.558     21.750    10.0      4.0    5.102993e-003    1.06     6.38
  -33.308     21.750    10.0      4.0    5.117682e-003    1.06     6.38
  -33.058     21.750    10.0      4.0    5.261921e-003    1.06     6.38
  -32.808     21.750    10.0      4.0    5.279290e-003    1.06     6.36
  -32.558     21.750    10.0      4.0    4.803597e-003    1.10     6.36
  -32.308     21.750    10.0      4.0    5.454670e-003    1.09     6.36
  -32.058     21.750    10.0      4.0    8.485654e-004    0.96     6.37
  -31.808     21.750    10.0      4.0    8.508710e-004    0.96     6.37
  -31.558     21.750    10.0      4.0    8.564002e-004    0.96     6.20
  -31.308     21.750    10.0      4.0    6.953284e-004    0.96     6.20
  -31.058     21.750    10.0      4.0    7.835372e-004    0.96     6.20
  -30.808     21.750    10.0      4.0    8.937484e-004    1.08     6.20
  -30.558     21.750    10.0      4.0    1.165875e-003    1.05     6.20
  -33.558     22.000    10.0      4.0    9.006789e-004    0.96     6.37
  -33.308     22.000    10.0      4.0    5.117682e-003    1.06     6.38
  -33.058     22.000    10.0      4.0    5.261921e-003    1.06     6.38
  -32.808     22.000    10.0      4.0    5.910761e-003    1.06     6.36
  -32.558     22.000    10.0      4.0    4.669331e-003    1.11     6.37
  -32.308     22.000    10.0      4.0    8.462437e-004    0.96     6.37
  -32.058     22.000    10.0      4.0    8.485654e-004    0.96     6.37
  -31.808     22.000    10.0      4.0    8.541022e-004    0.96     6.20
  -31.558     22.000    10.0      4.0    8.564002e-004    0.96     6.20
  -31.308     22.000    10.0      4.0    6.640855e-004    1.12     6.20
  -31.058     22.000    10.0      4.0    7.835372e-004    0.96     6.20
  -33.058     22.250    10.0      4.0    9.723989e-004    0.96     6.38
  -32.808     22.250    10.0      4.0    1.750234e-003    0.96     6.36
  -32.558     22.250    10.0      4.0    8.439059e-004    0.96     6.37
  -32.308     22.250    10.0      4.0    8.494574e-004    0.96     6.20
  -32.058     22.250    10.0      4.0    7.797506e-004    0.96     6.20
  -31.808     22.250    10.0      4.0    7.818692e-004    0.96     6.20
  -31.558     22.250    10.0      4.0    7.839729e-004    0.96     6.20
  -31.308     22.250    10.0      4.0    7.810998e-004    0.96     6.20
```

FAULT-TYPE SEISMOGENIC ZONES:

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FAULT #1

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     EDGES COORDINATES, Lat Long [DEG] & FAULT LENGTH [KM]
   -----------------------------------------------------------
          -32.19   18.88      -32.18   18.88         0.4

 Fault Length   Mmax   Segment Length   Mmax(segment)    Fault distance
------------------------------------------------------------------------
      0.4         4.6         0.1            3.7              10.0
```

FAULT #2

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     EDGES COORDINATES, Lat Long [DEG] & FAULT LENGTH [KM]
   -----------------------------------------------------------
          -32.19   18.88      -32.18   18.88         0.6

 Fault Length   Mmax   Segment Length   Mmax(segment)    Fault distance
------------------------------------------------------------------------
      0.6       4.9         0.1            3.9                10.0
```

```
                              FAULT #3
                              =========

                EDGES COORDINATES, Lat Long [DEG] & FAULT LENGTH [KM]
             -----------------------------------------------------------
                    -32.19   18.88      -32.18   18.88         0.7

      Fault  Length   Mmax   Segment Length   Mmax(segment)    Fault distance
      -----------------------------------------------------------------------
              0.7       4.9          0.1            4.0              10.0


                              FAULT #4
                              =========

                EDGES COORDINATES, Lat Long [DEG] & FAULT LENGTH [KM]
             -----------------------------------------------------------
                    -32.17   18.87      -32.20   18.89         3.4

       Fault Length   Mmax   Segment Length   Mmax(segment)    Fault distance
      -----------------------------------------------------------------------
              3.4       5.7          0.5            4.8              10.0

          Nr   Segment Length [KM]  Mmax(segment)  Lambda (for mag = 4.0)
          ---------------------------------------------------------------
                    1        0.1           3.7           0.0735
                    2        0.1           3.9           0.1250
                    3        0.1           4.0           0.1400
                    4        0.5           4.8           0.6615
```

Appendix D

Applied Ground Motion Prediction Equation

Ground Motion Prediction Equation #1

```
            GMPE-1: ATKINSON-BOORE (BSSA, vol.96, pp.2181-2205, 2006)
     =====================================================================

   ln[a(f)] = c1 + c2*mag + c3*mag^2 + (c4 + c5*mag)*f1 + (c6 + c7*mag)*f2 +
              (c8 + c9*mag)*f0 + c10*r + p*SD

   WHERE:

     a         = MEDIAN VALUE, HARD ROCK, AVERAGE HORIZONTAL COMPONENT PGA/ARS [g]
     f         = GROUND MOTION FREQUENCY. IF a = PGA, f = 99.9 [Hz]
     mag       = EARTHQUAKE MAGNITUDE Mw
     r         = HYPOCENTRAL DISTANCE (CLOSEST DISTANCE TO THE FAULT) [KM]
     f0        = MAX[log10(r0/r),0], r0 = 10 KM
     f1        = MIN[log10(r/r1],    r1 = 70 KM
     f2        = MAX[log10(r/r2),0], r2 = 140 KM
```

```
    p         = 0. IF p = 1, ln(a) = MEAN[ln(a)] + SD[ln(a)]
    c1,...,c10 = COEFFICIENTS; SD OF PREDICTED ln(a) = 0.69

                       ATTENUATION COEFFICIENTS
                    ==============================

Freq.(Hz)  c1    c2     c3     c4    c5     c6     c7     c8     c9     c10
----------------------------------------------------------------------------
   0.2   -5.41 1.710 -0.0901 -2.54 0.227 -1.270  0.116  0.979 -0.1770 -0.0002
   0.3   -5.79 1.920 -0.1070 -2.44 0.211 -1.160  0.102  1.010 -0.1820 -0.0002
   0.4   -6.17 2.210 -0.1350 -2.30 0.190 -0.986  0.079  0.968 -0.1770 -0.0003
   0.5   -6.18 2.300 -0.1440 -2.22 0.177 -0.937  0.071  0.952 -0.1770 -0.0003
   0.8   -5.72 2.320 -0.1510 -2.10 0.157 -0.820  0.052  0.856 -0.1660 -0.0004
   1.0   -5.27 2.260 -0.1480 -2.07 0.150 -0.813  0.047  0.826 -0.1620 -0.0005
   2.0   -3.22 1.830 -0.1200 -2.02 0.134 -0.813  0.044  0.884 -0.1750 -0.0008
   2.5   -2.44 1.650 -0.1080 -2.05 0.136 -0.843  0.045  0.739 -0.1560 -0.0009
   4.0   -1.12 1.340 -0.0872 -2.08 0.135 -0.971  0.056  0.614  0.1430 -0.0011
   5.0   -0.61 1.230 -0.0789 -2.09 0.131 -1.120  0.068  0.606 -0.1460 -0.0011
   8.0    0.21 1.050 -0.0666 -2.15 0.130 -1.610  0.105  0.427 -0.1300 -0.0012
  10.0    0.48 1.020 -0.0640 -2.20 0.127 -2.010  0.133  0.337 -0.1270 -0.0010
  20.0    1.11 0.972 -0.0620 -2.47 0.128 -3.390  0.214 -0.139 -0.0984 -0.0003
  25.2    1.26 0.968 -0.0623 -2.58 0.132 -3.640  0.228 -0.351 -0.0813 -0.0001
  40.0    1.52 0.960 -0.0635 -2.81 0.146 -3.650  0.236 -0.654 -0.0550 -0.0000
  99.0    0.91 0.983 -0.0660 -2.70 0.159 -2.800  0.212 -0.301 -0.0653 -0.0004
```

Ground Motion Prediction Equation #2

GMPE-2: Extensional Tectonic Regimes (SEA99, SPUDICH et al., 1999)

```
          ATTENUATION MODEL: SPUDICH et al. (1999)
               (Extensional Tectonic Regimes)
       ==============================================

  ln[a(f)] = c1 + c2*(mag-6) + c3*(mag-6)^2 + c4*r + c5*ln(r) + p*SD

  WHERE:

    a         = MEDIAN VALUE, AVERAGE HORIZONTAL COMPONENT PGA [g]
    f         = GROUND MOTION FREQUENCY. IF a = PGA, f = 99.9 [Hz]
    mag       = EARTHQUAKE MAGNITUDE Mw
    r         = sqrt(r_JB^2 + c6^2), r_JB= JOYNER-BOORE DISTANCE [KM]
    p         = 0. IF p = 1, ln(a) = MEAN[ln(a)] + SD[ln(a)]
    c1,...,c8 = COEFFICIENTS, WHERE sqrt(c7^2 + c8^2) IS SD OF ln(a)

                         ATTENUATION COEFFICIENTS
                      ==============================

Freq. (Hz)        c1        c2      c3       c4       c5       c6     c7     c8
--------------------------------------------------------------------------------
  99.0          0.688      0.527  0.000     0.00    -1.052   7.27   0.396  0.249
```

Appendix E

Results of PSHA. Tabulated values of mean activity rate, return periods and probability of exceedance in 1, 50, 100 and 1 000 years for specified values of PGA

GMPR-1. Scenario 1: Four faults identified in vicinity of dam wall are not active

```
==============================================
 File       : info_PSHA_att#1 (no faults).txt
 Created on : 01-Mar-2011 16:32:08
==============================================


 PROBABILISTIC SEISMIC HAZARD ASSESSMENT FOR A SELECTED SITE
              BY THE CORNELL-McGUIRE PROCEDURE
 ============================================================

 THE APPLIED METHODOLOGY IS DESCRIBED IN THE DOCUMENT:

    "Recommendation for Probabilistic Seismic Hazard Analysis:
     Guidance on Uncertainty and Use of Experts",

     Prepared by:

     Senior Seismic Hazard Analysis Committee (SSHAC),
     R.J. Budnitz (Chairman), G. Apostolakis, D.M. Boore, L.S. Cluff,
     K.J. Coppersmith, C.A. Cornell, and P.A. Morris.

     Lawrence Livermore National Laboratory.

     Prepared for:

     U.S. Nuclear Regulatory Commission, U.S. Department of Energy and
     Electric Power Research Institute.

     NUREG/CR-6372, UCRL-ID-122160, vol.1, April 1997


 THE CODE REQUIRES TWO INPUT FILES:

   FILE CONTAINING SITE-SPECIFIC INFORMATION:
   ------------------------------------------

       - Site coordinates, LATITUDE & LONGITUDE [DEG]

       - MINIMUM VALUE OF ANNUAL PROBABILITY OF EXCEEDANCE of PGA for which
         PSHA calculations are to be performed. Suggested values:
         for nuclear facilities, between 10^(-6) and 10^(-4),
         for large water reservoirs/dams between 10^(-4) and 10^(-3).

       - 3 TIME INTERVALS for which PSHA will be performed.
         Suggested values: 50, 100 and 1000 years.

       - Parameter controlling the ACCURACY of numerical integration. If its value = 1,
```

```
         the accuracy of integration is LOW, but computation time is SHORT.
         If its value = 2, accuracy of integration is MODERATE, but computation
         time is LONGER. If its value is 3, accuracy of integration is
         HIGHEST, but computations require SIGNIFICANTLY more time.

       - Parameter providing provision for increase/decrease of seismicity.

       - Two parameters controlling UNCERTAINTY of the assumed seismicity model.
         First parameter controls uncertainty of b-value in the FREQUENCY-MAGNITUDE,
         Gutenberg-Richter relation. Second parameter controls uncertainty
         of the level of seismicity described by the mean activity rate LAMBDA.

       - Parameter controlling predicted value of Ground Motion.
         If its value is = 1, in all calculations the MEAN value of
         ln(Ground Motion) is used. If its value is = 2, the predicted,
         mean value of ln(Ground Motion) is increased by its STANDARD DEVIATION


   FILE CONTAINING INFORMATION ON SEISMIC SOURCES IN THE VICINITY OF THE SITE
   --------------------------------------------------------------------------

       Each seismic source is described by 7 parameters:

       (1) latitude [DEG]
       (2) longitude [DEG]
       (3) depth [KM] of seismic source,
       (4) minimum earthquake magnitude Mmin
       (5) Mean seismic activity rate LAMBDA
       (6) b-value of the frequency-magnitude Gutenberg-Richter relation
       (7) MAXIMUM, seismic source-characteristic EQ-e magnitude Mmax.


==========================================================================

 PROGRAM NAME     : HS_C_McG (H = Hazard; S = Site; C = Cornell; McG = McGuire)

 WRITTEN          : 15 SEP 2007 by A.K.
 REVISED          : 27 SEP 2007 by A.K.
                  : 30 SEP 2007 by A.K.
                  : 01 OCT 2007 by A.K.
                  : 20 FEB 2008 by A.K.
                  : 12 MAY 2008 by A.K.
                  : 21 JUN 2008 by A.K.
                  : 15 SEP 2009 by A.K.
                  : 28 OCT 2010 by A.K.

 REVISION         : 1.12

==========================================================================

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==========================================================================


  PROBABILISTIC SEISMIC HAZARD ASSESSMENT BY CORNELL-McGuire PROCEDURE
 ======================================================================

     The applied approach takes into account ground motion variability
     by integrating across the scatter in the attenuation equation


 NAME OF THE SITE: Clanwilliam Dam (no faults)
```

```
ATTENUATION MODEL #3: ATKINSON & BOORE (2006)

SITE COORDINATES (LATITUDE)                =  -32.183 [DEG]
SITE COORDINATES (LONGITUDE)               =   18.875 [DEG]

MINIMUM ANNUAL PROBABILITY OF EXCEEDANCE   = 1.000e-005 [DEG]

PSHA IS CALCULATED FOR TIME INTERVALS      = 50 100 and 1000 YEARS

ACCURACY OF NUMERICAL INTEGRATION: LOW
MAGNITUDE INTEGRATION INTERVAL   = 0.5

PROVISION FOR INDUCED SEISMICITY: REQUIRED
MULTIPLICATIVE FACTOR OF LAMBDA = 1

MODEL UNCERTAINTY OF THE b-VALUE              = 25 [per cent]
MODEL UNCERTAINTY OF THE SITE-SPECIFIC LAMBDA = 25 [per cent]

ALL CALCULATIONS ARE PERFORMED FOR MEAN VALUE OF ln[PGA/ARS]

NAME OF INPUT FILE WITH PARAMETERS OF SEISMIC SOURCES: ss_no_faults.txt

Max EXPECTED PGA AT THE SITE = 0.176 [g] (FROM SEISMIC SOURCE #172)


                            SEISMIC HAZARD
        ==========================================================

PGA[g]  Lambda[EQ/Y]     RP[Y]         Prob(T = 1  50  100  1000 [Y])

0.010   6.2509e-002   1.5998e+001   0.060596 0.956083 0.998071 1.000000
0.020   2.2251e-002   4.4943e+001   0.022005 0.671273 0.891938 1.000000
0.030   1.1528e-002   8.6745e+001   0.011462 0.438083 0.684249 0.999990
0.040   7.0139e-003   1.4257e+002   0.006989 0.295803 0.504107 0.999101
0.050   4.6829e-003   2.1354e+002   0.004672 0.208753 0.373929 0.990748
0.060   3.3268e-003   3.0059e+002   0.003321 0.153243 0.283002 0.964093
0.070   2.4718e-003   4.0456e+002   0.002469 0.116258 0.219000 0.915567
0.080   1.8999e-003   5.2634e+002   0.001898 0.090622 0.173032 0.850416
0.090   1.4995e-003   6.6687e+002   0.001498 0.072235 0.139252 0.776767
0.100   1.2089e-003   8.2720e+002   0.001208 0.058655 0.113869 0.701475
0.110   9.9158e-004   1.0085e+003   0.000991 0.048370 0.094401 0.629011
0.120   8.2506e-004   1.2120e+003   0.000825 0.040413 0.079194 0.561789
0.130   6.9480e-004   1.4393e+003   0.000695 0.034143 0.067121 0.500825
0.140   5.9112e-004   1.6917e+003   0.000591 0.029123 0.057399 0.446292
0.150   5.0735e-004   1.9710e+003   0.000507 0.025048 0.049469 0.397910
0.160   4.3878e-004   2.2790e+003   0.000439 0.021700 0.042930 0.355180
0.170   3.8203e-004   2.6176e+003   0.000382 0.018920 0.037483 0.317527
0.180   3.3459e-004   2.9887e+003   0.000335 0.016590 0.032905 0.284368
0.190   2.9458e-004   3.3946e+003   0.000295 0.014621 0.029029 0.255158
0.200   2.6058e-004   3.8375e+003   0.000261 0.012945 0.025722 0.229399
0.210   2.3149e-004   4.3198e+003   0.000231 0.011508 0.022883 0.206650
0.220   2.0644e-004   4.8441e+003   0.000206 0.010269 0.020432 0.186523
0.230   1.8474e-004   5.4129e+003   0.000185 0.009195 0.018305 0.168684
0.240   1.6586e-004   6.0290e+003   0.000166 0.008259 0.016450 0.152838
0.250   1.4935e-004   6.6955e+003   0.000149 0.007440 0.014824 0.138736
0.260   1.3486e-004   7.4153e+003   0.000135 0.006720 0.013395 0.126158
0.270   1.2207e-004   8.1917e+003   0.000122 0.006085 0.012133 0.114918
0.280   1.1077e-004   9.0280e+003   0.000111 0.005523 0.011015 0.104852
0.290   1.0073e-004   9.9278e+003   0.000101 0.005024 0.010022 0.095820
0.300   9.1787e-005   1.0895e+004   0.000092 0.004579 0.009137 0.087701
0.310   8.3804e-005   1.1933e+004   0.000084 0.004181 0.008345 0.080388
0.320   7.6654e-005   1.3046e+004   0.000077 0.003825 0.007636 0.073790
0.330   7.0236e-005   1.4238e+004   0.000070 0.003506 0.006999 0.067826
0.340   6.4461e-005   1.5513e+004   0.000064 0.003218 0.006425 0.062427
0.350   5.9252e-005   1.6877e+004   0.000059 0.002958 0.005908 0.057531
0.360   5.4544e-005   1.8334e+004   0.000055 0.002723 0.005440 0.053083
0.370   5.0281e-005   1.9888e+004   0.000050 0.002511 0.005015 0.049037
0.380   4.6412e-005   2.1546e+004   0.000046 0.002318 0.004630 0.045352
0.390   4.2896e-005   2.3312e+004   0.000043 0.002143 0.004280 0.041989
0.400   3.9695e-005   2.5192e+004   0.000040 0.001983 0.003962 0.038918
```

```
0.410   3.6776e-005   2.7192e+004   0.000037 0.001837 0.003671 0.036108
0.420   3.4109e-005   2.9317e+004   0.000034 0.001704 0.003405 0.033534
0.430   3.1670e-005   3.1575e+004   0.000032 0.001582 0.003162 0.031174
0.440   2.9436e-005   3.3972e+004   0.000029 0.001471 0.002939 0.029007
0.450   2.7387e-005   3.6514e+004   0.000027 0.001368 0.002735 0.027015
0.460   2.5505e-005   3.9209e+004   0.000026 0.001274 0.002547 0.025182
0.470   2.3774e-005   4.2063e+004   0.000024 0.001188 0.002375 0.023493
0.480   2.2180e-005   4.5086e+004   0.000022 0.001108 0.002216 0.021936
0.490   2.0711e-005   4.8283e+004   0.000021 0.001035 0.002069 0.020498
0.500   1.9356e-005   5.1665e+004   0.000019 0.000967 0.001934 0.019169
0.510   1.8103e-005   5.5238e+004   0.000018 0.000905 0.001809 0.017941
0.520   1.6946e-005   5.9013e+004   0.000017 0.000847 0.001693 0.016803
0.530   1.5874e-005   6.2997e+004   0.000016 0.000793 0.001586 0.015748
0.540   1.4881e-005   6.7202e+004   0.000015 0.000744 0.001487 0.014770
0.550   1.3960e-005   7.1635e+004   0.000014 0.000698 0.001395 0.013863
0.560   1.3105e-005   7.6309e+004   0.000013 0.000655 0.001310 0.013019
0.570   1.2310e-005   8.1232e+004   0.000012 0.000615 0.001230 0.012235
0.580   1.1572e-005   8.6416e+004   0.000012 0.000578 0.001157 0.011505
0.590   1.0885e-005   9.1873e+004   0.000011 0.000544 0.001088 0.010826
0.600   1.0244e-005   9.7614e+004   0.000010 0.000512 0.001024 0.010192
0.610   9.6478e-006   1.0365e+005   0.000010 0.000482 0.000964 0.009601


           UNIFORM ACCELERATION RERSPONSE SPECTRA
        ============================================


               Return Period = 100 [Y]
            ----------------------------------

        Period [SEC]  Freq [Hz]    UARS [g]

             1.00       1.00       0.010
             0.50       2.00       0.015
             0.40       2.50       0.019
             0.25       4.00       0.030
             0.20       5.00       0.041
             0.13       8.00       0.058
             0.10      10.00       0.067
             0.05      20.00       0.072
             0.04      25.20       0.070
             0.03      40.00       0.062
             0.01      99.00       0.025


               Return Period = 200 [Y]
            ----------------------------------

        Period [SEC]  Freq [Hz]    UARS [g]

             1.25       0.80       0.010
             1.00       1.00       0.011
             0.50       2.00       0.021
             0.40       2.50       0.029
             0.25       4.00       0.052
             0.20       5.00       0.065
             0.13       8.00       0.079
             0.10      10.00       0.096
             0.05      20.00       0.110
             0.04      25.20       0.108
             0.03      40.00       0.094
             0.01      99.00       0.042


               Return Period = 475 [Y]
            ----------------------------------

        Period [SEC]  Freq [Hz]    UARS [g]

             1.25       0.80       0.011
```

```
     1.00       1.00       0.012
     0.50       2.00       0.038
     0.40       2.50       0.059
     0.25       4.00       0.076
     0.20       5.00       0.096
     0.13       8.00       0.122
     0.10      10.00       0.148
     0.05      20.00       0.171
     0.04      25.20       0.170
     0.03      40.00       0.156
     0.01      99.00       0.072

       Return Period = 1000 [Y]
    ----------------------------------

Period [SEC]  Freq [Hz]    UARS [g]

     2.00       0.50       0.010
     1.25       0.80       0.011
     1.00       1.00       0.016
     0.50       2.00       0.063
     0.40       2.50       0.075
     0.25       4.00       0.111
     0.20       5.00       0.133
     0.13       8.00       0.171
     0.10      10.00       0.210
     0.05      20.00       0.245
     0.04      25.20       0.246
     0.03      40.00       0.228
     0.01      99.00       0.109

       Return Period = 10000 [Y]
    ----------------------------------

Period [SEC]  Freq [Hz]    UARS [g]

     2.50       0.40       0.010
     2.00       0.50       0.011
     1.25       0.80       0.028
     1.00       1.00       0.062
     0.50       2.00       0.150
     0.40       2.50       0.189
     0.25       4.00       0.271
     0.20       5.00       0.338
     0.13       8.00       0.433
     0.10      10.00       0.534
     0.05      20.00       0.642
     0.04      25.20       0.650
     0.03      40.00       0.616
     0.01      99.00       0.289

       Return Period = 100000 [Y]
    ----------------------------------

Period [SEC]  Freq [Hz]    UARS [g]

     4.00       0.25       0.010
     2.50       0.40       0.012
     2.00       0.50       0.026
     1.25       0.80       0.079
     1.00       1.00       0.125
     0.50       2.00       0.317
     0.40       2.50       0.401
     0.25       4.00       0.567
     0.20       5.00       0.707
     0.13       8.00       0.895
     0.10      10.00       1.106
     0.05      20.00       1.328
```

```
     0.04      25.20       1.346
     0.03      40.00       1.277
     0.01      99.00       0.603


       Return Period = 1000000 [Y]
    ----------------------------------

Period [SEC]  Freq [Hz]    UARS [g]

     5.00       0.20       0.010
     4.00       0.25       0.010
     2.50       0.40       0.034
     2.00       0.50       0.069
     1.25       0.80       0.159
     1.00       1.00       0.232
     0.50       2.00       0.572
     0.40       2.50       0.720
     0.25       4.00       1.009
     0.20       5.00       1.257
     0.13       8.00       1.581
     0.10      10.00       1.953
     0.05      20.00       2.338
     0.04      25.20       2.368
     0.03      40.00       2.248
     0.01      99.00       1.064
```

GMPR-1. Scenario 2: Four faults identified in vicinity of dam wall are active

```
 ================================================
 File       : info_PSHA_att#1 (with faults).txt
 Created on : 01-Mar-2011 16:50:09
 ================================================


 PROBABILISTIC SEISMIC HAZARD ASSESSMENT FOR A SELECTED SITE
              BY THE CORNELL-McGUIRE PROCEDURE
 ============================================================

 THE APPLIED METHODOLOGY IS DESCRIBED IN THE DOCUMENT:

    "Recommendation for Probabilistic Seismic Hazard Analysis:
     Guidance on Uncertainty and Use of Experts",

     Prepared by:

     Senior Seismic Hazard Analysis Committee (SSHAC),
     R.J. Budnitz (Chairman), G. Apostolakis, D.M. Boore, L.S. Cluff,
     K.J. Coppersmith, C.A. Cornell, and P.A. Morris.

     Lawrence Livermore National Laboratory.

     Prepared for:

     U.S. Nuclear Regulatory Commission, U.S. Department of Energy and
     Electric Power Research Institute.

     NUREG/CR-6372, UCRL-ID-122160, vol.1, April 1997


 THE CODE REQUIRES TWO INPUT FILES:

   FILE CONTAINING SITE-SPECIFIC INFORMATION:
   ------------------------------------------

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       - MINIMUM VALUE OF ANNUAL PROBABILITY OF EXCEEDANCE of PGA for which
         PSHA calculations are to be performed. Suggested values:
         for nuclear facilities, between 10^(-6) and 10^(-4),
         for large water reservoirs/dams between 10^(-4) and 10^(-3).

       - 3 TIME INTERVALS for which PSHA will be performed.
         Suggested values: 50, 100 and 1000 years.

       - Parameter controlling the ACCURACY of numerical integration. If its value = 1,
         the accuracy of integration is LOW, but computation time is SHORT.
         If its value = 2, accuracy of integration is MODERATE, but computation
         time is LONGER. If its value is 3, accuracy of integration is
         HIGHEST, but computations require SIGNIFICANTLY more time.

       - Parameter providing provision for increase/decrease of seismicity.

       - Two parameters controlling UNCERTAINTY of the assumed seismicity model.
         First parameter controls uncertainty of b-value in the FREQUENCY-MAGNITUDE,
         Gutenberg-Richter relation. Second parameter controls uncertainty
         of the level of seismicity described by the mean activity rate LAMBDA.
```

```
       - Parameter controlling predicted value of Ground Motion.
         If its value is = 1, in all calculations the MEAN value of
         ln(Ground Motion) is used. If its value is = 2, the predicted,
         mean value of ln(Ground Motion) is increased by its STANDARD DEVIATION


   FILE CONTAINING INFORMATION ON SEISMIC SOURCES IN THE VICINITY OF THE SITE
   --------------------------------------------------------------------------

       Each seismic source is described by 7 parameters:

       (1) latitude [DEG]
       (2) longitude [DEG]
       (3) depth [KM] of seismic source,
       (4) minimum earthquake magnitude Mmin
       (5) Mean seismic activity rate LAMBDA
       (6) b-value of the frequency-magnitude Gutenberg-Richter relation
       (7) MAXIMUM, seismic source-characteristic EQ-e magnitude Mmax.


==========================================================================

 PROGRAM NAME     : HS_C_McG (H = Hazard; S = Site; C = Cornell; McG = McGuire)

 WRITTEN          : 15 SEP 2007 by A.K.
 REVISED          : 27 SEP 2007 by A.K.
                  : 30 SEP 2007 by A.K.
                  : 01 OCT 2007 by A.K.
                  : 20 FEB 2008 by A.K.
                  : 12 MAY 2008 by A.K.
                  : 21 JUN 2008 by A.K.
                  : 15 SEP 2009 by A.K.
                  : 28 OCT 2010 by A.K.

 REVISION         : 1.12

==========================================================================

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 8 Birch Str. Clubview, ext.2
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 South Africa

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==========================================================================


  PROBABILISTIC SEISMIC HAZARD ASSESSMENT BY CORNELL-McGUIRE PROCEDURE
 ======================================================================

     The applied approach takes into account ground motion variability
     by integrating across the scatter in the attenuation equation


 NAME OF THE SITE: Clanwilliam Dam (with faults)

 ATTENUATION MODEL #3: ATKINSON & BOORE (2006)

 SITE COORDINATES (LATITUDE)                = -32.183 [DEG]
 SITE COORDINATES (LONGITUDE)               =  18.875 [DEG]
 MINIMUM ANNUAL PROBABILITY OF EXCEEDANCE   = 1.000e-005 [DEG]
 PSHA IS CALCULATED FOR TIME INTERVALS      = 50 100 and 1000 YEARS
 ACCURACY OF NUMERICAL INTEGRATION: LOW
 MAGNITUDE INTEGRATION INTERVAL   = 0.5
 PROVISION FOR INDUCED SEISMICITY: REQUIRED
 MULTIPLICATIVE FACTOR OF LAMBDA = 1
 MODEL UNCERTAINTY OF THE b-VALUE              = 25 [per cent]
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MODEL UNCERTAINTY OF THE SITE-SPECIFIC LAMBDA = 25 [per cent]
ALL CALCULATIONS ARE PERFORMED FOR MEAN VALUE OF ln[PGA/ARS]
NAME OF INPUT FILE WITH PARAMETERS OF SEISMIC SOURCES: ss.txt
Max EXPECTED PGA AT THE SITE = 0.374 [g] (FROM SEISMIC SOURCE #448)


                          SEISMIC HAZARD
        ==========================================================

PGA[g]  Lambda[EQ/Y]     RP[Y]        Prob(T = 1  50  100  1000 [Y])

0.010   8.2491e-002   1.2123e+001   0.079180 0.983829 0.999738 1.000000
0.020   4.1943e-002   2.3842e+001   0.041075 0.877193 0.984919 1.000000
0.030   3.0455e-002   3.2835e+001   0.029996 0.781888 0.952427 1.000000
0.040   2.4807e-002   4.0311e+001   0.024502 0.710718 0.916316 1.000000
0.050   2.1152e-002   4.7278e+001   0.020929 0.652704 0.879386 1.000000
0.060   1.8417e-002   5.4297e+001   0.018249 0.601825 0.841456 1.000000
0.070   1.6215e-002   6.1670e+001   0.016085 0.555483 0.802405 1.000000
0.080   1.4374e-002   6.9569e+001   0.014271 0.512621 0.762461 0.999999
0.090   1.2804e-002   7.8101e+001   0.012722 0.472809 0.722070 0.999997
0.100   1.1449e-002   8.7344e+001   0.011384 0.435858 0.681744 0.999989
0.110   1.0272e-002   9.7356e+001   0.010219 0.401650 0.641977 0.999965
0.120   9.2431e-003   1.0819e+002   0.009201 0.370077 0.603196 0.999903
0.130   8.3411e-003   1.1989e+002   0.008306 0.341016 0.565740 0.999761
0.140   7.5472e-003   1.3250e+002   0.007519 0.314330 0.529857 0.999472
0.150   6.8462e-003   1.4607e+002   0.006823 0.289871 0.495717 0.998936
0.160   6.2254e-003   1.6063e+002   0.006206 0.267483 0.463419 0.998021
0.170   5.6740e-003   1.7624e+002   0.005658 0.247008 0.433004 0.996566
0.180   5.1830e-003   1.9294e+002   0.005170 0.228293 0.404469 0.994389
0.190   4.7446e-003   2.1077e+002   0.004733 0.211189 0.377778 0.991301
0.200   4.3521e-003   2.2977e+002   0.004343 0.195557 0.352871 0.987120
0.210   3.9999e-003   2.5001e+002   0.003992 0.181264 0.329672 0.981682
0.220   3.6830e-003   2.7151e+002   0.003676 0.168191 0.308093 0.974854
0.230   3.3974e-003   2.9435e+002   0.003392 0.156224 0.288042 0.966539
0.240   3.1392e-003   3.1855e+002   0.003134 0.145262 0.269423 0.956683
0.250   2.9054e-003   3.4418e+002   0.002901 0.135213 0.252143 0.945275
0.260   2.6933e-003   3.7129e+002   0.002690 0.125991 0.236107 0.932341
0.270   2.5004e-003   3.9994e+002   0.002497 0.117520 0.221229 0.917946
0.280   2.3246e-003   4.3017e+002   0.002322 0.109731 0.207421 0.902181
0.290   2.1642e-003   4.6206e+002   0.002162 0.102562 0.194606 0.885162
0.300   2.0176e-003   4.9565e+002   0.002016 0.095957 0.182706 0.867021
0.310   1.8832e-003   5.3100e+002   0.001881 0.089864 0.171653 0.847901
0.320   1.7600e-003   5.6819e+002   0.001758 0.084238 0.161380 0.827952
0.330   1.6467e-003   6.0727e+002   0.001645 0.079038 0.151829 0.807320
0.340   1.5425e-003   6.4830e+002   0.001541 0.074226 0.142942 0.786153
0.350   1.4464e-003   6.9136e+002   0.001445 0.069768 0.134669 0.764590
0.360   1.3578e-003   7.3651e+002   0.001357 0.065635 0.126962 0.742763
0.370   1.2758e-003   7.8382e+002   0.001275 0.061798 0.119777 0.720793
0.380   1.1999e-003   8.3337e+002   0.001199 0.058233 0.113075 0.698791
0.390   1.1297e-003   8.8522e+002   0.001129 0.054917 0.106819 0.676857
0.400   1.0644e-003   9.3946e+002   0.001064 0.051831 0.100975 0.655079
0.410   1.0039e-003   9.9616e+002   0.001003 0.048954 0.095511 0.633537
0.420   9.4751e-004   1.0554e+003   0.000947 0.046271 0.090401 0.612296
0.430   8.9505e-004   1.1173e+003   0.000895 0.043766 0.085617 0.591414
0.440   8.4616e-004   1.1818e+003   0.000846 0.041425 0.081135 0.570940
0.450   8.0054e-004   1.2492e+003   0.000800 0.039236 0.076933 0.550913
0.460   7.5793e-004   1.3194e+003   0.000758 0.037187 0.072992 0.531364
0.470   7.1810e-004   1.3926e+003   0.000718 0.035268 0.069292 0.512321
0.480   6.8082e-004   1.4688e+003   0.000681 0.033468 0.065816 0.493800
0.490   6.4591e-004   1.5482e+003   0.000646 0.031780 0.062549 0.475815
0.500   6.1318e-004   1.6308e+003   0.000613 0.030194 0.059476 0.458377
0.510   5.8248e-004   1.7168e+003   0.000582 0.028704 0.056584 0.441487
0.520   5.5364e-004   1.8062e+003   0.000553 0.027303 0.053860 0.425149
0.530   5.2655e-004   1.8992e+003   0.000526 0.025984 0.051292 0.409358
0.540   5.0106e-004   1.9958e+003   0.000501 0.024742 0.048871 0.394112
0.550   4.7707e-004   2.0961e+003   0.000477 0.023571 0.046587 0.379402
0.560   4.5448e-004   2.2003e+003   0.000454 0.022468 0.044430 0.365219
0.570   4.3318e-004   2.3085e+003   0.000433 0.021426 0.042393 0.351554
0.580   4.1309e-004   2.4208e+003   0.000413 0.020442 0.040467 0.338395
0.590   3.9412e-004   2.5373e+003   0.000394 0.019513 0.038646 0.325729
0.600   3.7621e-004   2.6581e+003   0.000376 0.018635 0.036922 0.313543
```

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0.610   3.5928e-004   2.7833e+003   0.000359 0.017804 0.035290 0.301823
0.620   3.4327e-004   2.9131e+003   0.000343 0.017017 0.033745 0.290555
0.630   3.2812e-004   3.0476e+003   0.000328 0.016272 0.032280 0.279725
0.640   3.1378e-004   3.1870e+003   0.000314 0.015566 0.030891 0.269318
0.650   3.0019e-004   3.3313e+003   0.000300 0.014897 0.029573 0.259320
0.660   2.8730e-004   3.4806e+003   0.000287 0.014263 0.028322 0.249716
0.670   2.7508e-004   3.6352e+003   0.000275 0.013660 0.027134 0.240492
0.680   2.6349e-004   3.7952e+003   0.000263 0.013088 0.026005 0.231634
0.690   2.5248e-004   3.9607e+003   0.000252 0.012545 0.024932 0.223128
0.700   2.4202e-004   4.1319e+003   0.000242 0.012028 0.023912 0.214961
0.710   2.3208e-004   4.3088e+003   0.000232 0.011537 0.022941 0.207119
0.720   2.2263e-004   4.4917e+003   0.000223 0.011070 0.022017 0.199590
0.730   2.1364e-004   4.6808e+003   0.000214 0.010625 0.021137 0.192361
0.740   2.0508e-004   4.8761e+003   0.000205 0.010202 0.020299 0.185419
0.750   1.9693e-004   5.0779e+003   0.000197 0.009798 0.019501 0.178755
0.760   1.8917e-004   5.2862e+003   0.000189 0.009414 0.018739 0.172355
0.770   1.8177e-004   5.5014e+003   0.000182 0.009047 0.018013 0.166210
0.780   1.7472e-004   5.7234e+003   0.000175 0.008698 0.017320 0.160308
0.790   1.6799e-004   5.9527e+003   0.000168 0.008364 0.016659 0.154640
0.800   1.6157e-004   6.1892e+003   0.000162 0.008046 0.016027 0.149195
0.810   1.5544e-004   6.4332e+003   0.000155 0.007742 0.015424 0.143966
0.820   1.4959e-004   6.6848e+003   0.000150 0.007452 0.014848 0.138941
0.830   1.4400e-004   6.9443e+003   0.000144 0.007174 0.014297 0.134114
0.840   1.3866e-004   7.2119e+003   0.000139 0.006909 0.013770 0.129476
0.850   1.3355e-004   7.4877e+003   0.000134 0.006655 0.013266 0.125018
0.860   1.2867e-004   7.7720e+003   0.000129 0.006413 0.012784 0.120733
0.870   1.2399e-004   8.0650e+003   0.000124 0.006180 0.012323 0.116614
0.880   1.1952e-004   8.3668e+003   0.000120 0.005958 0.011881 0.112654
0.890   1.1524e-004   8.6776e+003   0.000115 0.005745 0.011458 0.108847
0.900   1.1114e-004   8.9978e+003   0.000111 0.005541 0.011052 0.105185
0.910   1.0721e-004   9.3275e+003   0.000107 0.005346 0.010664 0.101663
0.920   1.0345e-004   9.6669e+003   0.000103 0.005159 0.010291 0.098275
0.930   9.9837e-005   1.0016e+004   0.000100 0.004979 0.009934 0.095015
0.940   9.6377e-005   1.0376e+004   0.000096 0.004807 0.009591 0.091878
0.950   9.3058e-005   1.0746e+004   0.000093 0.004642 0.009263 0.088859
0.960   8.9874e-005   1.1127e+004   0.000090 0.004484 0.008947 0.085953
0.970   8.6817e-005   1.1518e+004   0.000087 0.004331 0.008644 0.083156
0.980   8.3884e-005   1.1921e+004   0.000084 0.004185 0.008353 0.080462
0.990   8.1066e-005   1.2336e+004   0.000081 0.004045 0.008074 0.077868
1.000   7.8360e-005   1.2762e+004   0.000078 0.003910 0.007805 0.075369
1.010   7.5760e-005   1.3199e+004   0.000076 0.003781 0.007547 0.072962
1.020   7.3262e-005   1.3650e+004   0.000073 0.003656 0.007299 0.070642
1.030   7.0860e-005   1.4112e+004   0.000071 0.003537 0.007061 0.068407
1.040   6.8550e-005   1.4588e+004   0.000069 0.003422 0.006832 0.066253
1.050   6.6329e-005   1.5076e+004   0.000066 0.003311 0.006611 0.064177
1.060   6.4192e-005   1.5578e+004   0.000064 0.003204 0.006399 0.062175
1.070   6.2135e-005   1.6094e+004   0.000062 0.003102 0.006194 0.060244
1.080   6.0156e-005   1.6623e+004   0.000060 0.003003 0.005998 0.058382
1.090   5.8250e-005   1.7167e+004   0.000058 0.002908 0.005808 0.056586
1.100   5.6416e-005   1.7726e+004   0.000056 0.002817 0.005626 0.054854
1.110   5.4648e-005   1.8299e+004   0.000055 0.002729 0.005450 0.053182
1.120   5.2946e-005   1.8887e+004   0.000053 0.002644 0.005281 0.051568
1.130   5.1305e-005   1.9491e+004   0.000051 0.002562 0.005117 0.050011
1.140   4.9723e-005   2.0111e+004   0.000050 0.002483 0.004960 0.048507
1.150   4.8199e-005   2.0747e+004   0.000048 0.002407 0.004808 0.047056
1.160   4.6729e-005   2.1400e+004   0.000047 0.002334 0.004662 0.045654
1.170   4.5311e-005   2.2070e+004   0.000045 0.002263 0.004521 0.044300
1.180   4.3944e-005   2.2756e+004   0.000044 0.002195 0.004385 0.042992
1.190   4.2624e-005   2.3461e+004   0.000043 0.002129 0.004253 0.041729
1.200   4.1351e-005   2.4183e+004   0.000041 0.002065 0.004127 0.040508
1.210   4.0122e-005   2.4924e+004   0.000040 0.002004 0.004004 0.039328
1.220   3.8936e-005   2.5683e+004   0.000039 0.001945 0.003886 0.038187
1.230   3.7790e-005   2.6462e+004   0.000038 0.001888 0.003772 0.037085
1.240   3.6683e-005   2.7260e+004   0.000037 0.001832 0.003662 0.036019
1.250   3.5615e-005   2.8078e+004   0.000036 0.001779 0.003555 0.034988
1.260   3.4582e-005   2.8917e+004   0.000035 0.001728 0.003452 0.033991
1.270   3.3584e-005   2.9776e+004   0.000034 0.001678 0.003353 0.033026
1.280   3.2620e-005   3.0656e+004   0.000033 0.001630 0.003257 0.032093
1.290   3.1687e-005   3.1558e+004   0.000032 0.001583 0.003164 0.031191
1.300   3.0786e-005   3.2482e+004   0.000031 0.001538 0.003074 0.030317
1.310   2.9915e-005   3.3429e+004   0.000030 0.001495 0.002987 0.029472
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1.320   2.9072e-005   3.4398e+004   0.000029 0.001453 0.002903 0.028653
1.330   2.8256e-005   3.5391e+004   0.000028 0.001412 0.002822 0.027861
1.340   2.7467e-005   3.6407e+004   0.000027 0.001372 0.002743 0.027093
1.350   2.6704e-005   3.7448e+004   0.000027 0.001334 0.002667 0.026350
1.360   2.5965e-005   3.8513e+004   0.000026 0.001297 0.002593 0.025631
1.370   2.5250e-005   3.9604e+004   0.000025 0.001262 0.002522 0.024934
1.380   2.4557e-005   4.0721e+004   0.000025 0.001227 0.002453 0.024258
1.390   2.3887e-005   4.1864e+004   0.000024 0.001194 0.002386 0.023604
1.400   2.3238e-005   4.3033e+004   0.000023 0.001161 0.002321 0.022970
1.410   2.2609e-005   4.4230e+004   0.000023 0.001130 0.002258 0.022355
1.420   2.2000e-005   4.5455e+004   0.000022 0.001099 0.002198 0.021760
1.430   2.1410e-005   4.6708e+004   0.000021 0.001070 0.002139 0.021182
1.440   2.0838e-005   4.7990e+004   0.000021 0.001041 0.002082 0.020622
1.450   2.0284e-005   4.9301e+004   0.000020 0.001014 0.002026 0.020079
1.460   1.9746e-005   5.0642e+004   0.000020 0.000987 0.001973 0.019553
1.470   1.9226e-005   5.2014e+004   0.000019 0.000961 0.001921 0.019042
1.480   1.8721e-005   5.3417e+004   0.000019 0.000936 0.001870 0.018546
1.490   1.8231e-005   5.4852e+004   0.000018 0.000911 0.001821 0.018066
1.500   1.7756e-005   5.6319e+004   0.000018 0.000887 0.001774 0.017599
1.510   1.7296e-005   5.7818e+004   0.000017 0.000864 0.001728 0.017147
1.520   1.6849e-005   5.9352e+004   0.000017 0.000842 0.001683 0.016708
1.530   1.6415e-005   6.0919e+004   0.000016 0.000820 0.001640 0.016281
1.540   1.5995e-005   6.2521e+004   0.000016 0.000799 0.001598 0.015867
1.550   1.5586e-005   6.4159e+004   0.000016 0.000779 0.001557 0.015465
1.560   1.5190e-005   6.5833e+004   0.000015 0.000759 0.001518 0.015075
1.570   1.4805e-005   6.7543e+004   0.000015 0.000740 0.001479 0.014696
1.580   1.4432e-005   6.9291e+004   0.000014 0.000721 0.001442 0.014328
1.590   1.4069e-005   7.1076e+004   0.000014 0.000703 0.001406 0.013971
1.600   1.3717e-005   7.2901e+004   0.000014 0.000686 0.001371 0.013624
1.610   1.3375e-005   7.4765e+004   0.000013 0.000669 0.001337 0.013286
1.620   1.3043e-005   7.6669e+004   0.000013 0.000652 0.001303 0.012958
1.630   1.2720e-005   7.8614e+004   0.000013 0.000636 0.001271 0.012640
1.640   1.2407e-005   8.0600e+004   0.000012 0.000620 0.001240 0.012330
1.650   1.2102e-005   8.2629e+004   0.000012 0.000605 0.001209 0.012029
1.660   1.1806e-005   8.4701e+004   0.000012 0.000590 0.001180 0.011737
1.670   1.1519e-005   8.6817e+004   0.000012 0.000576 0.001151 0.011452
1.680   1.1239e-005   8.8977e+004   0.000011 0.000562 0.001123 0.011176
1.690   1.0967e-005   9.1182e+004   0.000011 0.000548 0.001096 0.010907
1.700   1.0703e-005   9.3434e+004   0.000011 0.000535 0.001070 0.010646
1.710   1.0446e-005   9.5733e+004   0.000010 0.000522 0.001044 0.010391
1.720   1.0196e-005   9.8080e+004   0.000010 0.000510 0.001019 0.010144
1.730   9.9527e-006   1.0048e+005   0.000010 0.000498 0.000995 0.009903


           UNIFORM ACCELERATION RERSPONSE SPECTRA
        ============================================

                Return Period = 100 [Y]
             ----------------------------------

        Period [SEC]  Freq [Hz]    UARS [g]

             1.00       1.00       0.010
             0.50       2.00       0.022
             0.40       2.50       0.033
             0.25       4.00       0.065
             0.20       5.00       0.085
             0.13       8.00       0.126
             0.10      10.00       0.164
             0.05      20.00       0.240
             0.04      25.20       0.258
             0.03      40.00       0.272
             0.01      99.00       0.112


                Return Period = 200 [Y]
             ----------------------------------

        Period [SEC]  Freq [Hz]    UARS [g]
```

```
     1.25       0.80       0.010
     1.00       1.00       0.012
     0.50       2.00       0.037
     0.40       2.50       0.060
     0.25       4.00       0.098
     0.20       5.00       0.132
     0.13       8.00       0.199
     0.10      10.00       0.261
     0.05      20.00       0.391
     0.04      25.20       0.422
     0.03      40.00       0.450
     0.01      99.00       0.182


       Return Period = 475 [Y]
    ----------------------------------

Period [SEC]  Freq [Hz]    UARS [g]

     1.25       0.80       0.011
     1.00       1.00       0.016
     0.50       2.00       0.067
     0.40       2.50       0.091
     0.25       4.00       0.159
     0.20       5.00       0.214
     0.13       8.00       0.317
     0.10      10.00       0.413
     0.05      20.00       0.623
     0.04      25.20       0.673
     0.03      40.00       0.719
     0.01      99.00       0.292


       Return Period = 1000 [Y]
    ----------------------------------

Period [SEC]  Freq [Hz]    UARS [g]

     2.00       0.50       0.010
     1.25       0.80       0.014
     1.00       1.00       0.024
     0.50       2.00       0.097
     0.40       2.50       0.133
     0.25       4.00       0.225
     0.20       5.00       0.303
     0.13       8.00       0.444
     0.10      10.00       0.578
     0.05      20.00       0.870
     0.04      25.20       0.939
     0.03      40.00       1.004
     0.01      99.00       0.411


       Return Period = 10000 [Y]
    ----------------------------------

Period [SEC]  Freq [Hz]    UARS [g]

     2.50       0.40       0.010
     2.00       0.50       0.013
     1.25       0.80       0.055
     1.00       1.00       0.081
     0.50       2.00       0.253
     0.40       2.50       0.339
     0.25       4.00       0.546
     0.20       5.00       0.720
     0.13       8.00       1.019
     0.10      10.00       1.325
     0.05      20.00       1.966
     0.04      25.20       2.120
     0.03      40.00       2.261
```

```
     0.01      99.00       0.929


       Return Period = 100000 [Y]
    ----------------------------------

Period [SEC]  Freq [Hz]    UARS [g]

     4.00       0.25       0.010
     2.50       0.40       0.014
     2.00       0.50       0.042
     1.25       0.80       0.112
     1.00       1.00       0.172
     0.50       2.00       0.498
     0.40       2.50       0.666
     0.25       4.00       1.047
     0.20       5.00       1.369
     0.13       8.00       1.908
     0.10      10.00       2.478
     0.05      20.00       3.651
     0.04      25.20       3.936
     0.03      40.00       4.191
     0.01      99.00       1.727


       Return Period = 1000000 [Y]
    ----------------------------------

Period [SEC]  Freq [Hz]    UARS [g]

     5.00       0.20       0.010
     4.00       0.25       0.010
     2.50       0.40       0.050
     2.00       0.50       0.079
     1.25       0.80       0.190
     1.00       1.00       0.299
     0.50       2.00       0.846
     0.40       2.50       1.125
     0.25       4.00       1.756
     0.20       5.00       2.290
     0.13       8.00       3.169
     0.10      10.00       4.115
     0.05      20.00       6.043
     0.04      25.20       6.512
     0.03      40.00       6.927
     0.01      99.00       2.860
```

GMPR-2. Scenario 1: Four faults identified in vicinity of dam wall are not active

```
============================================
 File       : info_PSHA_att#2_no_faults.txt
 Created on : 01-Mar-2011 18:17:28
============================================


 PROBABILISTIC SEISMIC HAZARD ASSESSMENT FOR A SELECTED SITE
              BY THE CORNELL-McGUIRE PROCEDURE
 ============================================================

 THE APPLIED METHODOLOGY IS DESCRIBED IN THE DOCUMENT:

    "Recommendation for Probabilistic Seismic Hazard Analysis:
     Guidance on Uncertainty and Use of Experts",

     Prepared by:

     Senior Seismic Hazard Analysis Committee (SSHAC),
     R.J. Budnitz (Chairman), G. Apostolakis, D.M. Boore, L.S. Cluff,
     K.J. Coppersmith, C.A. Cornell, and P.A. Morris.

     Lawrence Livermore National Laboratory.

     Prepared for:

     U.S. Nuclear Regulatory Commission, U.S. Department of Energy and
     Electric Power Research Institute.

     NUREG/CR-6372, UCRL-ID-122160, vol.1, April 1997


 THE CODE REQUIRES TWO INPUT FILES:

   FILE CONTAINING SITE-SPECIFIC INFORMATION:
   -----------------------------------------

       - Site coordinates, LATITUDE & LONGITUDE [DEG]

       - MINIMUM VALUE OF ANNUAL PROBABILITY OF EXCEEDANCE of PGA for which
         PSHA calculations are to be performed. Suggested values:
         for nuclear facilities, between 10^(-6) and 10^(-4),
         for large water reservoirs/dams between 10^(-4) and 10^(-3).

       - 3 TIME INTERVALS for which PSHA will be performed.
         Suggested values: 50, 100 and 1000 years.

       - Parameter controlling the ACCURACY of numerical integration. If its value = 1,
         the accuracy of integration is LOW, but computation time is SHORT.
         If its value = 2, accuracy of integration is MODERATE, but computation
         time is LONGER. If its value is 3, accuracy of integration is
         HIGHEST, but computations require SIGNIFICANTLY more time.

       - Parameter providing provision for increase/decrease of seismicity.

       - Two parameters controlling UNCERTAINTY of the assumed seismicity model.
         First parameter controls uncertainty of b-value in the FREQUENCY-MAGNITUDE,
         Gutenberg-Richter relation. Second parameter controls uncertainty
         of the level of seismicity described by the mean activity rate LAMBDA.

       - Parameter controlling predicted value of Ground Motion.
         If its value is = 1, in all calculations the MEAN value of
         ln(Ground Motion) is used. If its value is = 2, the predicted,
         mean value of ln(Ground Motion) is increased by its STANDARD DEVIATION
```

```
   FILE CONTAINING INFORMATION ON SEISMIC SOURCES IN THE VICINITY OF THE SITE
   --------------------------------------------------------------------------

       Each seismic source is described by 7 parameters:

       (1) latitude [DEG]
       (2) longitude [DEG]
       (3) depth [KM] of seismic source,
       (4) minimum earthquake magnitude Mmin
       (5) Mean seismic activity rate LAMBDA
       (6) b-value of the frequency-magnitude Gutenberg-Richter relation
       (7) MAXIMUM, seismic source-characteristic EQ-e magnitude Mmax.


==========================================================================

 PROGRAM NAME     : HS_C_McG (H = Hazard; S = Site; C = Cornell; McG = McGuire)

 WRITTEN          : 15 SEP 2007 by A.K.
 REVISED          : 27 SEP 2007 by A.K.
                  : 30 SEP 2007 by A.K.
                  : 01 OCT 2007 by A.K.
                  : 20 FEB 2008 by A.K.
                  : 12 MAY 2008 by A.K.
                  : 21 JUN 2008 by A.K.
                  : 15 SEP 2009 by A.K.
                  : 28 OCT 2010 by A.K.

 REVISION         : 1.12

==========================================================================

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 8 Birch Str. Clubview, ext.2
 Centurion  0157
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 E-mail :  andrzej.kijko@up.ac.za/andrzej.kijko@gmail.com

==========================================================================


  PROBABILISTIC SEISMIC HAZARD ASSESSMENT BY CORNELL-McGUIRE PROCEDURE
 ======================================================================

     The applied approach takes into account ground motion variability
     by integrating across the scatter in the attenuation equation


 NAME OF THE SITE: Clanwilliam Att #2 (no faults)

 ATTENUATION MODEL #9: Extensional Tectonic Regimes (SEA99, SPUDICH et al., 1999)

 SITE COORDINATES (LATITUDE)                =  -32.183 [DEG]
 SITE COORDINATES (LONGITUDE)               =   18.875 [DEG]

 MINIMUM ANNUAL PROBABILITY OF EXCEEDANCE   = 1.000e-005 [DEG]

 PSHA IS CALCULATED FOR TIME INTERVALS      = 50 100 and 1000 YEARS

 ACCURACY OF NUMERICAL INTEGRATION: LOW
 MAGNITUDE INTEGRATION INTERVAL   = 0.5

 PROVISION FOR INDUCED SEISMICITY: REQUIRED
 MULTIPLICATIVE FACTOR OF LAMBDA = 1

 MODEL UNCERTAINTY OF THE b-VALUE              = 25 [per cent]
 MODEL UNCERTAINTY OF THE SITE-SPECIFIC LAMBDA = 25 [per cent]
```

```
ALL CALCULATIONS ARE PERFORMED FOR MEAN VALUE OF ln[PGA/ARS]

NAME OF INPUT FILE WITH PARAMETERS OF SEISMIC SOURCES: ss_no_faults.txt

Max EXPECTED PGA AT THE SITE = 0.091 [g] (FROM SEISMIC SOURCE #172)


                             SEISMIC HAZARD
        ==========================================================

PGA[g]  Lambda[EQ/Y]     RP[Y]         Prob(T = 1  50  100  1000 [Y])

0.010   1.5044e-001   6.6474e+000   0.139667 0.999459 1.000000 1.000000
0.020   3.8378e-002   2.6057e+001   0.037651 0.853231 0.978459 1.000000
0.030   1.6231e-002   6.1610e+001   0.016100 0.555834 0.802716 1.000000
0.040   8.3462e-003   1.1981e+002   0.008311 0.341184 0.565962 0.999763
0.050   4.6898e-003   2.1323e+002   0.004679 0.209026 0.374360 0.990811
0.060   2.7724e-003   3.6070e+002   0.002769 0.129442 0.242128 0.937489
0.070   1.6997e-003   5.8834e+002   0.001698 0.081474 0.156310 0.817262
0.080   1.0736e-003   9.3145e+002   0.001073 0.052264 0.101797 0.658222
0.090   6.9586e-004   1.4371e+003   0.000696 0.034195 0.067220 0.501355
0.100   4.6142e-004   2.1672e+003   0.000461 0.022807 0.045094 0.369615
0.110   3.1222e-004   3.2029e+003   0.000312 0.015490 0.030739 0.268177
0.120   2.1508e-004   4.6494e+003   0.000215 0.010697 0.021279 0.193525
0.130   1.5055e-004   6.6422e+003   0.000151 0.007499 0.014942 0.139767
0.140   1.0689e-004   9.3553e+003   0.000107 0.005330 0.010632 0.101376
0.150   7.6863e-005   1.3010e+004   0.000077 0.003836 0.007657 0.073983
0.160   5.5904e-005   1.7888e+004   0.000056 0.002791 0.005575 0.054370
0.170   4.1080e-005   2.4343e+004   0.000041 0.002052 0.004100 0.040248
0.180   3.0470e-005   3.2820e+004   0.000030 0.001522 0.003042 0.030010
0.190   2.2792e-005   4.3874e+004   0.000023 0.001139 0.002277 0.022535
0.200   1.7182e-005   5.8199e+004   0.000017 0.000859 0.001717 0.017036
0.210   1.3046e-005   7.6652e+004   0.000013 0.000652 0.001304 0.012961
0.220   9.9711e-006   1.0029e+005   0.000010 0.000498 0.000997 0.009922
```

GMPR-2. Scenario 2: Four faults identified in vicinity of dam wall are active

```
==============================================
 File       : info_PSHA_att#2_with_faults.txt
 Created on : 01-Mar-2011 18:22:56
==============================================


 PROBABILISTIC SEISMIC HAZARD ASSESSMENT FOR A SELECTED SITE
              BY THE CORNELL-McGUIRE PROCEDURE
 ============================================================

 THE APPLIED METHODOLOGY IS DESCRIBED IN THE DOCUMENT:

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     Guidance on Uncertainty and Use of Experts",

     Prepared by:

     Senior Seismic Hazard Analysis Committee (SSHAC),
     R.J. Budnitz (Chairman), G. Apostolakis, D.M. Boore, L.S. Cluff,
     K.J. Coppersmith, C.A. Cornell, and P.A. Morris.

     Lawrence Livermore National Laboratory.

     Prepared for:

     U.S. Nuclear Regulatory Commission, U.S. Department of Energy and
     Electric Power Research Institute.

     NUREG/CR-6372, UCRL-ID-122160, vol.1, April 1997


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         for large water reservoirs/dams between 10^(-4) and 10^(-3).

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         Suggested values: 50, 100 and 1000 years.

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       - Two parameters controlling UNCERTAINTY of the assumed seismicity model.
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         of the level of seismicity described by the mean activity rate LAMBDA.

       - Parameter controlling predicted value of Ground Motion.
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         mean value of ln(Ground Motion) is increased by its STANDARD DEVIATION
```

```
   FILE CONTAINING INFORMATION ON SEISMIC SOURCES IN THE VICINITY OF THE SITE
   --------------------------------------------------------------------------

       Each seismic source is described by 7 parameters:

       (1) latitude [DEG]
       (2) longitude [DEG]
       (3) depth [KM] of seismic source,
       (4) minimum earthquake magnitude Mmin
       (5) Mean seismic activity rate LAMBDA
       (6) b-value of the frequency-magnitude Gutenberg-Richter relation
       (7) MAXIMUM, seismic source-characteristic EQ-e magnitude Mmax.


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                  : 15 SEP 2009 by A.K.
                  : 28 OCT 2010 by A.K.

 REVISION         : 1.12

==========================================================================

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==========================================================================


  PROBABILISTIC SEISMIC HAZARD ASSESSMENT BY CORNELL-McGUIRE PROCEDURE
 =======================================================================

    The applied approach takes into account ground motion variability
    by integrating across the scatter in the attenuation equation


 NAME OF THE SITE: Clanwilliam Att #2 (with faults)

 ATTENUATION MODEL #9: Extensional Tectonic Regimes (SEA99, SPUDICH et al., 1999)

 SITE COORDINATES (LATITUDE)              =  -32.183 [DEG]
 SITE COORDINATES (LONGITUDE)             =   18.875 [DEG]

 MINIMUM ANNUAL PROBABILITY OF EXCEEDANCE = 1.000e-005 [DEG]

 PSHA IS CALCULATED FOR TIME INTERVALS    = 50 100 and 1000 YEARS

 ACCURACY OF NUMERICAL INTEGRATION: LOW
 MAGNITUDE INTEGRATION INTERVAL   = 0.5

 PROVISION FOR INDUCED SEISMICITY: REQUIRED
 MULTIPLICATIVE FACTOR OF LAMBDA = 1

 MODEL UNCERTAINTY OF THE b-VALUE            = 25 [per cent]
```

```
MODEL UNCERTAINTY OF THE SITE-SPECIFIC LAMBDA = 25 [per cent]

ALL CALCULATIONS ARE PERFORMED FOR MEAN VALUE OF ln[PGA/ARS]

NAME OF INPUT FILE WITH PARAMETERS OF SEISMIC SOURCES: ss.txt

Max EXPECTED PGA AT THE SITE = 0.120 [g] (FROM SEISMIC SOURCE #448)


                             SEISMIC HAZARD
        ==========================================================

PGA[g]  Lambda[EQ/Y]     RP[Y]         Prob(T = 1  50  100  1000 [Y])

0.010   1.7043e-001   5.8674e+000   0.156701 0.999801 1.000000 1.000000
0.020   5.8213e-002   1.7178e+001   0.056551 0.945559 0.997036 1.000000
0.030   3.5044e-002   2.8536e+001   0.034437 0.826608 0.969935 1.000000
0.040   2.5029e-002   3.9954e+001   0.024718 0.713908 0.918151 1.000000
0.050   1.8636e-002   5.3660e+001   0.018463 0.606155 0.844886 1.000000
0.060   1.3953e-002   7.1671e+001   0.013856 0.502235 0.752230 0.999999
0.070   1.0423e-002   9.5942e+001   0.010369 0.406161 0.647355 0.999970
0.080   7.7694e-003   1.2871e+002   0.007739 0.321908 0.540191 0.999578
0.090   5.7894e-003   1.7273e+002   0.005773 0.251338 0.439505 0.996940
0.100   4.3202e-003   2.3147e+002   0.004311 0.194272 0.350802 0.986702
0.110   3.2331e-003   3.0930e+002   0.003228 0.149267 0.276253 0.960566
0.120   2.4291e-003   4.1168e+002   0.002426 0.114369 0.215657 0.911883
0.130   1.8334e-003   5.4544e+002   0.001832 0.087593 0.167513 0.840128
0.140   1.3907e-003   7.1906e+002   0.001390 0.067173 0.129833 0.751099
0.150   1.0604e-003   9.4301e+002   0.001060 0.051641 0.100615 0.653696
0.160   8.1292e-004   1.2301e+003   0.000813 0.039831 0.078075 0.556437
0.170   6.2649e-004   1.5962e+003   0.000626 0.030839 0.060727 0.465535
0.180   4.8535e-004   2.0604e+003   0.000485 0.023976 0.047376 0.384520
0.190   3.7794e-004   2.6459e+003   0.000378 0.018720 0.037089 0.314731
0.200   2.9578e-004   3.3809e+003   0.000296 0.014680 0.029145 0.256046
0.210   2.3259e-004   4.2994e+003   0.000233 0.011562 0.022991 0.207523
0.220   1.8376e-004   5.4419e+003   0.000184 0.009146 0.018208 0.167864
0.230   1.4583e-004   6.8573e+003   0.000146 0.007265 0.014477 0.135696
0.240   1.1623e-004   8.6035e+003   0.000116 0.005795 0.011556 0.109731
0.250   9.3024e-005   1.0750e+004   0.000093 0.004640 0.009259 0.088829
0.260   7.4748e-005   1.3378e+004   0.000075 0.003730 0.007447 0.072022
0.270   6.0292e-005   1.6586e+004   0.000060 0.003010 0.006011 0.058510
0.280   4.8810e-005   2.0487e+004   0.000049 0.002438 0.004869 0.047638
0.290   3.9655e-005   2.5218e+004   0.000040 0.001981 0.003958 0.038879
0.300   3.2326e-005   3.0935e+004   0.000032 0.001615 0.003227 0.031809
0.310   2.6437e-005   3.7825e+004   0.000026 0.001321 0.002640 0.026091
0.320   2.1689e-005   4.6105e+004   0.000022 0.001084 0.002167 0.021456
0.330   1.7848e-005   5.6029e+004   0.000018 0.000892 0.001783 0.017690
0.340   1.4729e-005   6.7892e+004   0.000015 0.000736 0.001472 0.014621
0.350   1.2190e-005   8.2036e+004   0.000012 0.000609 0.001218 0.012116
0.360   1.0115e-005   9.8860e+004   0.000010 0.000506 0.001011 0.010064
0.370   8.4157e-006   1.1883e+005   0.000008 0.000421 0.000841 0.008380
```

Appendix F

Attenuation of vertical peak acceleration (by N. A. Abrahamson and J.J. Litehiser)

Attenuation of vertical peak acceleration

N. A. ABRAHAMSON and J. J. LITEHISER

BECHTEL CIVIL, INC., P.O. BOX 3965, SAN FRANCISCO, CALIFORNIA 94119

Peak vertical accelerations from a suite of 585 strong ground motion records from 76 worldwide earthquakes are fit to an attenuation model that has a magnitude dependent shape. The regression uses a two-step procedure that is a hybrid of the Joyner and Boore (1981) and Campbell (1981) regression methods. The resulting vertical attenuation relation is

$$log_{10}a_v(g) = -1.15 + 0.245M - 1.096log_{10}(r + e^{0.256M}) + 0.096F - 0.0011Er,$$

where M is magnitude, r is the distance in kilometers to the closest approach of the zone of energy release, F is a dummy variable that is 1 for reverse or reverse oblique events and 0 otherwise, and E is a dummy variable that is 1 for interplate events and 0 for intraplate events. The standard error of $\log_{10}a_v$ is 0.296.

Because the vertical to horizontal acceleration ratio is also sought, the attenuation of the horizontal peaks from the same suite of records is also obtained using the same regression procedure. The resulting horizontal attenuation relation is

$$log_{10}a_H(g) = -0.62 + 0.177M - 0.982log_{10}(r + e^{0.284M}) + 0.132F - 0.0008Er,$$

where a_H is the peak acceleration of the larger of the two horizontal components. The standard error of $\log_{10}a_H$ is 0.277.

The expected ratio of peak vertical to peak horizontal strong ground motion predicted by these equations is enveloped by the widely used rule-of-thumb value of two-thirds for earthquakes with magnitudes less than 7.0 and distances greater than 20 km. The expected ratio exceeds 1.0 for earthquakes with magnitudes greater than 8.0 at very short distances. The standard error of $\log_{10}(V/H)$ is 0.20, which is less than the standard error of either the vertical or horizontal acceleration. Therefore, the peak vertical and horizontal accelerations for a given record are strongly correlated and we can have more confidence in the predicted ratio than in either the predicted vertical or horizontal peaks.

Zutari (Pty) Ltd

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