DWS Report No. P WMA 09/E10/00/0417/8

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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 I Jan Dissels Scheme

October 2020

Department of Water and Sanitation
Directorate: Options Analysis

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 I: JAN DISSELS

October 2020

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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
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3	P WMA 09/E10/00/0417/3	Capacity Building & Training Year 2
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5	P WMA 09/E10/00/0417/5	Distribution of Additional Available Water
6		Existing Infrastructure and Current Agricultural Development Sub-Report
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8		Suitable Agricultural areas and Land Ownership Report
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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

Aurecon South Africa (Pty) Ltd was appointed by the Department of Water & Sanitation (DWS) to provide recommendations on the bulk conveyance infrastructure (new developments / upgrading / rehabilitation) required for the equitable distribution of the existing and additional water from the raised Clanwilliam Dam. As part of the wider study geotechnical investigations have been conducted at the most favourable schemes, namely Jan Dissels, Right Bank Canal and Ebenhaeser. These geotechnical investigations included the following elements:

- Geophysical (soil electrical resistivity) surveys.
- Test pitting.
- Field testing including Dynamic Cone Penetration (DCP) testing.
- Laboratory testing.
- Interpretation, analysis and reporting.

This report presents the findings of the **Jan Dissels Scheme** investigations. The findings for the Right Bank Canal and Ebenhaeser Schemes are presented in separate reports.

Scheme description

At the time of the geotechnical investigation, two sub-options were considered, namely Rising Main 1 and Rising Main 2, both pipelines ending at the balancing dam (that will most likely be a concrete reservoir). The geotechnical investigation therefore encompassed the following elements:

- **Rising Main (RM) Route 1** – pumping from an inlet directly from a raised Clanwilliam Dam basin.
- **Rising Main (RM) Route 2** – pumping from an outlet point provided downstream of the raised Clanwilliam Dam wall, on the right bank.
- **A balancing reservoir** – from where irrigation water can be gravitated to almost the entire area.

Regional geology

The underlying geology comprises quartzitic sandstone from the Table Mountain Group, Cape Supergroup, which is overlain by colluvium soils. The seismic hazard of the area is considered to be very low and the Peak Ground Acceleration (PGA) values range between 0.1g and 0.08g, with a 10% probability of being exceeded in a 50-year period.

Site investigations

Three of the thirteen test pits could not be excavated due to access constraints. The geotechnical conditions for the pump station from Rising Main 1 have therefore not been investigated in sufficient detail. The pump station could be a floating inlet, or it could be on the shore of the raised Clanwilliam Dam. According to the DCP data (from surface to 0.32 m) around this area, the soil consistency ranges from medium dense to very dense as depth increases.

The *general* geological profile along the Rising Main 2 pipeline route is characterised by soil strata with thickness up to 2.30 m. Various horizons are recognised, including topsoil, colluvium, residual sand from quartzitic sandstone with gravels, cobbles and occasional residual quartzitic sandstone. Bedrock comprises moderately to slightly weathered, thickly and sub-horizontally bedded, very closely to moderately jointed sandstone. Joints are <20 mm open and in-filled with silty sand.

The overlying colluvium horizon occurs in "pockets" of variable thickness on the footprint of the reservoir as well as along Rising Main 1. The material can generally be classified as "Soft Excavation" in terms of SANS 1200D: Earthworks, (SANS, 1988). Hard to very hard rock quartzitic sandstone scattered outcrop is evident towards the north western end (closer to the existing dam wall) of the pipeline route. The hard rock quartzitic sandstone also occurs at irregular depths in test pits excavated along the remainder of the pipeline route. This material will be classified as "Hard Excavation" in terms of SANS 1200D.

Recommendations

Major sidewall collapse occurred in the colluvium layer, which often led to the termination of the test pit excavations. In addition, sidewall stability can worsen drastically if water is to be encountered in excavations, whether in the form of a perched water table or surface water run-off, which may accidently be draining into excavations during construction. In addition, the gravelly sand stratum of residual quartzitic sandstone is of particular concern in terms of the stability of cut slopes. Where the cut slopes intersect this horizon, there is a likelihood that ravelling, and spalling will occur. 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 and boulders 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.

Construction of the concrete reservoir does not require deep cuts, i.e. < 1.5 m deep. Therefore, no slope stability issues are foreseen relating to the construction of the balancing reservoir.

To date, there has been no geotechnical focus on wider sources of construction materials, other than the *in-situ* materials encountered within the corridors investigated. Current investigations did not actively target the proving of potential hard rock sources that might be crushed to produce coarse aggregate. However, the laboratory test results and the results of the fieldwork were used to evaluate the suitability of the various on-site soils/rocks for use in the backfill (selected fill and main fill) of the trench excavation for the pipelines and as possible bedding material (selected granular material), classified according to AASHTO M-145 and SANS 1200 LB and 1200 DB.

According to the classifications, the colluvium is mainly suitable as bedding cradle and selected fill blanket, i.e. SC1 and SC2 bedding material types and the residual quartzitic sandstone is generally suitable for foundations. It should be noted that occasional sandy clay material (with a PI of 18%) within the residual quartzitic sandstone horizon was found in localized areas. This material is not suitable as bedding and backfill material.

A reinforced concrete slab foundation is a common approach for small reservoirs and is proposed for the Jan Dissels Scheme. Adequate bearing capacity may be obtained from the hard rock quartzitic sandstone bedrock that was intersected at a maximum depth of 1.10 m along the perimeter of the reservoir. Bedrock that will provide the desired bearing capacity is therefore found at shallow depths on the footprint. Blasting or trimming of hard rock will be required for the reservoir foundation to ensure a level foundation on the bedrock.

It should be noted that there are some apparent contradictions in the determined corrosivity potentials as associated with pH and soil conductivity results.

The low soil pH value as found in all samples suggests corrosive conditions, yet the lab results yielded conductivity values which are generally lower than 10 mS/m and therefore classified as non-corrosive.

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

At the time of the geotechnical investigation, there were still some uncertainties with regards to the design of the alternative pipeline routes, for example, whether the pipes to be constructed above or below natural ground level, the specifications of the pipes (steel or uPVC), and whether the pump station will be a floating inlet or on the shore of the Clanwilliam Dam.

It is therefore recommended that follow-up geotechnical investigations be conducted, specifically where insufficient data was obtained for the pump station. Follow-up investigations would also address aspects such as confirmation of the geological continuity (laterally and with depth) across the site. Any additional design optimisations would also require that appropriate geological and geotechnical investigations are carried out.

List of abbreviations

AASHTO	=	American Association of State and Highway Transport Officials
CH	=	Chainage
COLTO	=	Committee of Land Transport Officials
DCP	=	Dynamic Cone Penetrometer
DWS	=	Department of Water & Sanitation
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
PI	=	Plasticity Index
PR	=	Penetration Rate
SAICE	=	South African Institution of Civil Engineering
SANS	=	South African National Standards
TLB	=	Tractor-loader backhoe (light)
TP	=	Test pit, or trial pit
TRH	=	Technical Recommendations for Highways
USCS	=	Unified Soil Classification System
WPI	=	Weighted Plasticity Index
PSHA	=	Probabilistic Seismic Hazard Analysis

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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 Jan Dissels Scheme is located on the right bank of the Clanwilliam Dam, which is situated east of the N7 highway (**Figure 1**).

Only a brief outline of the Jan Dissels Scheme is provided below, solely as a reference to 'frame' the scope, and the findings, of the geotechnical investigations. Details of the scheme are to be found in the Conceptual Design Report and are not repeated unnecessarily here.

At the time of the geotechnical investigation, two sub-options were considered, namely Rising Main 1 and Rising Main 2 (both pipelines ending at a balancing reservoir). The geotechnical investigation therefore encompassed the following elements (**Figure 1**):

- **Rising Main (RM) Route 1 –** pumping directly from a raised Clanwilliam Dam basin. This option involves the construction of an approximately 650 m long, 500 mm diameter Rising Main pipeline from the 600 kW pump station to the balancing reservoir. The pump station could be a floating inlet or could be on the shore of the raised Clanwilliam Dam (above the 1:100 year flood line).
- **Rising Main (RM) Route 2 –** pumping from an outlet point provided downstream of the raised dam wall, on the right bank. This option involves the construction of an approximately 3620 m long Rising Main pipeline from the 600 kW pump station (located at an outlet point provided downstream the raised dam wall on the right bank) to the balancing reservoir.
- **A balancing reservoir –** from where irrigation water can be gravitated to almost the entire area. The dam capacity was sized for a 12-hour design flow storage of 11 616 m^3. The pumping head from the Clanwilliam Dam to the balancing dam, which is likely to be a concrete reservoir, is 114 m.

Figure 1: Layout of the Jan Dissels Scheme (RM = Rising Main)

3 Investigation methodology

3.1 Desk study and reconnaissance visit

A field reconnaissance visit was conducted by the Aurecon design team on 16th and 17th March 2020 when 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 Series:
  - Sheet 3118 Calvinia. Council for Geoscience, 2001.
  - Sheet 3218 Clanwilliam. Council for Geoscience, 1973.
- 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 Jan Dissels Scheme included both sub-options as outlined in Section 2.

A major complication with the execution of the fieldwork was experienced due to the national COVID 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

Preliminary test pit positions were determined in accordance with the Site Investigation Code of Practice (SAICE, 2010). An average test pit spacing of 300 m was targeted. In places, a closer spacing was utilised, for example at the balancing reservoir and proposed pump station sites. Preliminary positions were used for planning purposes, fully accepting that a level of flexibility was required, and where circumstances dictated, adjustments were made in the field. Not all planned test pits could be excavated, particularly the areas next to the Clanwilliam Dam where the topography was too rugged for TLB access.

Test pit positions were set out in the field using a hand-held GPS, and due allowance should be given to the accuracy of such devices. The GPS coordinates and termination depths of the test pits are presented in **Table 1**. A scheme layout plan indicating the test pit locations is attached in **Appendix A**, (Drawing No. 113834/0000/DRG/GG/0001/Rev A).

Table 1: Test pit details

Test pit	Coordinates (LO 19)		Termination depth (m)	Remarks	Proposed structure
	Y	X			
JD-TP01	-9845.766	-3565029.241	N/A	No access with TLB. DCP conducted	Pump station
JD-TP02	-9809.649	-3565059.334	N/A	No access with TLB. DCP conducted	
JD-TP03	-9751.194	-3564933.604	N/A	No access with TLB.	Rising main 1
JD-TP04	-9658.900	-3564843.359	1.00	Sidewall collapse and refusal on hard rock sandstone boulders at 1.00 m	
JD-TP05	-9596.640	-3564767.453	1.10	Refusal on hard rock quartzitic sandstone bedrock at 1.10 m	Balancing reservoir
JD-TP06	-9539.887	-3564762.964	1.00	Refusal on hard rock quartzitic sandstone bedrock at 1.00 m	
JD-TP07	-9586.517	-3564704.680	0.30	Refusal on medium hard rock sandstone bedrock at 0.30 m	
JD-TP08	-9750.552	-3564425.503	0.30	Refusal on very soft rock sandstone bedrock at 0.30 m	Rising main 2
JD-TP09	-9874.060	-3564148.974	1.80	Refusal on tightly packed colluvium gravel at 1.80 m	
JD-TP10	-9975.415	-3563855.079	0.70	Refusal on very soft rock sandstone bedrock at 0.70 m	

Test pit	Coordinates (LO 19)		Termination depth (m)	Remarks	Proposed structure
	Y	X			
JD-TP11	-10125.076	-3563580.466	1.40	Refusal on medium hard rock quartzitic sandstone bedrock at 1.40 m	Rising main 2
JD-TP12	-10340.863	-3563409.665	2.30	Sidewall collapse and refusal on soft rock sandstone bedrock at 2.30 m	
JD-TP13	-10510.768	-3563120.390	1.30	Refusal on hard rock quartzitic sandstone bedrock at 1.30 m	
JD-TP14	-10665.976	-3562908.242	2.10	Refusal on medium hard rock quartzitic sandstone bedrock at 2.10 m	
JD-TP15	-10870.431	-3562690.541	1.20	Sidewall collapse and refusal on very soft rock quartzitic sandstone bedrock at 1.20 m	
JD-TP16	-11097.635	-3562572.578	1.70	Sidewall collapse and refusal on quartzitic sandstone boulders at 1.70 m	
JD-TP17	-11534.026	-3562520.946	N/A	Exposed cut face profiled	
JD-TP18	-11637.004	-3562316.327	N/A	Exposed cut face profiled	
JD-TP19	-11739.255	-3562251.940	N/A	Exposed cut face profiled	
JD-TP20	-9707.280	-3564745.624	0.50	Refusal on hard rock sandstone bedrock at 0.50 m	Rising main 1
JD-TP21	-9787.896	-3564905.251	0.80	Sidewall collapse and refusal on sandstone boulders at 0.80 m	
JD-TP22	-11459.398	-3562217.798	0.50	Refusal on hard rock sandstone bedrock at 0.50 m	Rising main 2

Due consideration was given to the total number of test pits for the Bridging Study as a whole, the estimated fieldwork duration, as well as the overall project programme, and it was concluded that a single fieldwork team would not be optimal. Two field teams were subsequently decided upon; each led by a professionally registered engineering geologist. Each team comprised two persons, in compliance with the SAICE Code of Practice (SAICE, 2007).

Plant was provided by the Construction South team of the Department of Water and Sanitation (DWS), stationed at Clanwilliam Dam. This plant comprised two light tractor-loader backhoes (TLB's).

Test pits were excavated to 3 m depth, unless refusal was encountered at shallower depth, or the conditions were deemed unsafe. The test pits were profiled in-situ (up to a depth determined to be safe) by professionally registered engineering geologists, according to accepted South African practice (Jennings, Brink and Williams, 1973). A summary of soil and rock profile description terminology is provided in **Appendix B**.

Soil samples representative of the soil horizons were obtained from the test pits for laboratory testing. The test pit profiles with accompanying photographs are presented in **Appendix C**

3.2.3 In situ 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 a distance of 575 mm. The results are expressed as the penetration rate (PR) in mm per blow. DCP tests were conducted adjacent to the test pit positions to evaluate and correlate the stiffness of the soil profile.

Results obtained from the dynamic cone penetrometer (DCP) gives a rough indication of the consistency of the soil and of the allowable bearing pressures for shallow foundations. The relationship between the penetration rates, material description and allowable bearing pressure, as shown in **Table 2**, is regarded as a guideline for *non-cohesive soils*.

Table 2: Dynamic cone penetration correlation with allowable bearing pressure

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

The allowable bearing pressure should however be treated with considerable caution since it is a function of the type of structure (ridged or flexible) and the differential movements it can tolerate. In terms of differential movement, the magnitude of the blow count and its variation across the structure should also be considered.

Detailed results are included in **Appendix D** and summarised in Section 5.4.2.

3.2.4 Laboratory testing

A competitive bidding process was carried out to appoint geotechnical testing laboratories.

The majority of the laboratory tests have been carried out by Steyn Wilson Laboratories (Pty) Ltd. Approximately 10% of the sample quantities were submitted to another independent laboratory, Labco South Africa (Pty) Ltd., essentially for quality control purposes.

It was apparent that the results from Steyn Wilson Laboratories did not include the following:

- Weighted Plasticity Index
- Grading Modulus
- Uniformity coefficient
- Coefficient of curvature

The results from the laboratory were therefore used to calculate the abovementioned parameters.

Tests conducted, and the quantities are summarised below (**Table 3**). Detailed laboratory test results from the laboratories as well as re-calculations by Zutari are included in **Appendix E** and are summarised within the text.

Table 3: Laboratory test summary

Test	Quantity
Foundation Indicators, comprising grading analyses (both sieve as well as hydrometer) as well as Atterberg limits and Linear Shrinkage	14
Mod ASSHTO Compaction and CBR	7
Chemical tests, including pH and conductivity	8
Direct shear tests	5

3.2.5 Geophysical surveys

Soil electrical resistivity surveys were conducted by specialist geophysicists from Aurecon (now Zutari).

These geophysical surveys were conducted specifically to address the question of potential corrosiveness of an envisaged steel pipe.

Detailed description of the methodologies, and 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, to determine the corrosiveness of the soil along the proposed pipeline route.

4 General geology

4.1 Stratigraphy and lithology

The 1:250 000 scale geological map 3218 Clanwilliam (Council for Geoscience, 1973) indicates that the area around both options for the Jan Dissels Scheme, i.e. Rising Main (RM) Route 1, pumping from a floating inlet directly from a raised Clanwilliam Dam and Rising Main (RM) Route 2 from the raised dam wall, are underlain by quartzitic sandstone with thin shale and conglomerate lenses of the Table Mountain Group, Cape Supergroup (**Figure 2**).

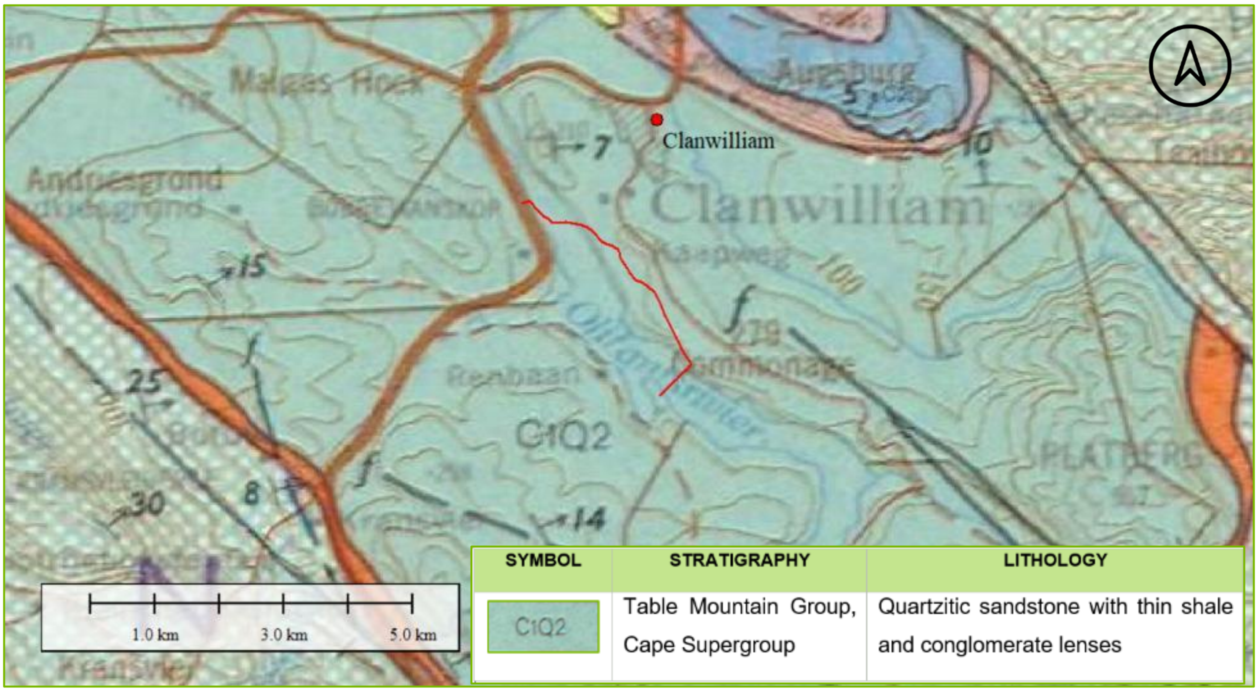

Figure 2: Jan Dissels Scheme, extract from the 1:250 000 scale geological map 3218 Clanwilliam (Council for Geoscience, 1973)

4.2 Structural geology

The Cape Supergroup rocks in the vicinity of the Clanwilliam Dam are marked by major north-westerly trending faults that are secondary to the Cape Fold Belt, which is a fold and thrust belt of late Palaeozoic Age. Smaller dip, step and strike thrust faults are present locally. The Cape Fold Belt affected the sequence of sedimentary rock layers of the Cape Supergroup through faulting, folding and subsequent weathering, which have produced a rugged mountainous terrain characterised by a sequence of elevated ridges and peaks around the dam area.

In terms of the folding, the area around the Clanwilliam Dam is a syncline with the sedimentary strata on either side dipping at gentle angles (14° to 25°) towards the dam.

4.3 Seismicity and seismic hazard

Structural geology is inextricably linked to the natural seismicity, and to the seismic hazard. Part of the Western Cape in general is recognised as a zone of elevated seismic hazard (**Figure 3**), in a large way due to the earthquake recorded in the Tulbagh area in 1969.

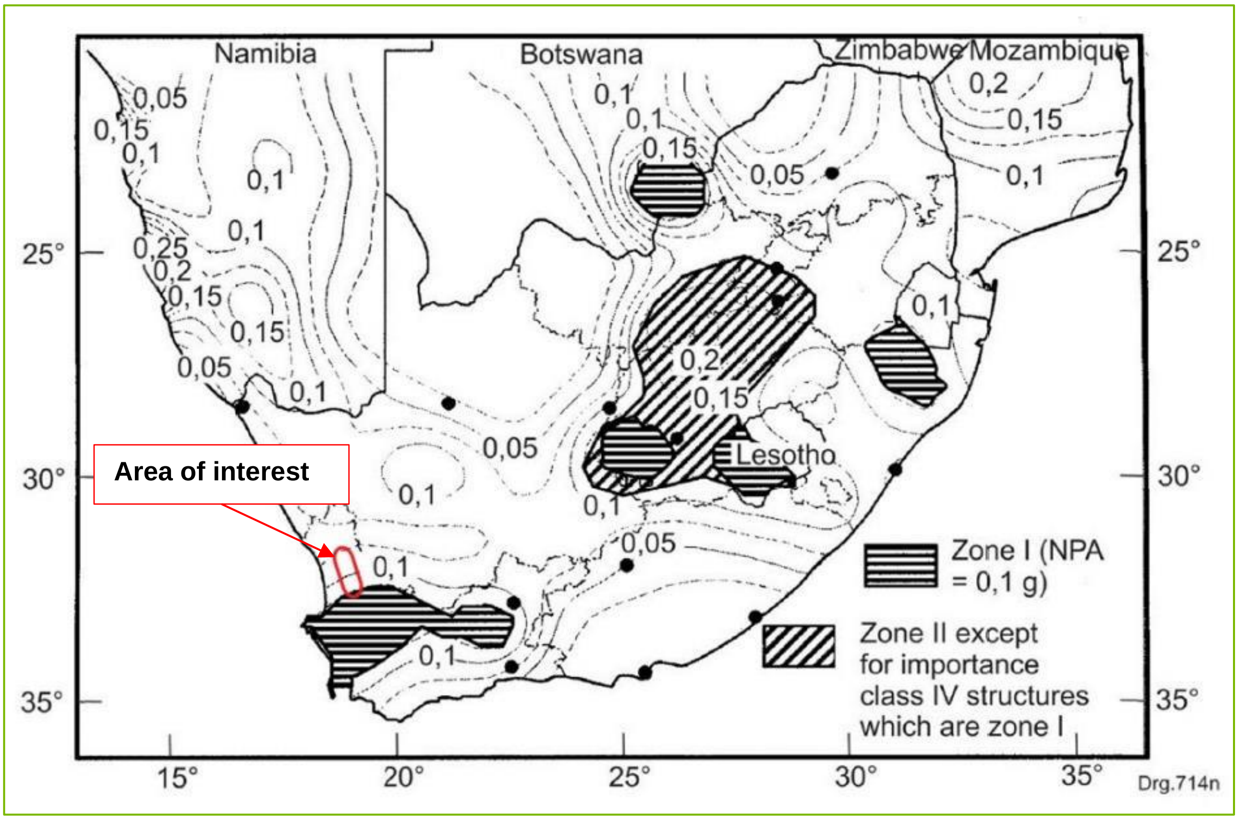

Figure 3: Seismic hazard, after SANS10160-4:2017, indicating PGA with a 10% probability of being exceeded in a 50-year period

The area of interest for this study, however, lies to the north of the elevated zone as shown below (**Figure 3**). This area is characterised by Peak Ground Acceleration (PGA) values between 0.1g and 0.08g which equates to a low seismic hazard.

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 Aurecon for DWS (then the Department of Water Affairs), and is included in this report as **Appendix G.**

A brief summary follows. Full details including analytical procedures, methodology, results and detailed discussions are presented in the PHSA report.

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.

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 taken into account 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) MCE are listed below in **Table 4**.

Table 4: Expected values for OBE, MDE and MCE (after logic tree formalism)

	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 study area can be classified as arid to semi-arid climate with relatively low annual rainfall, which increases from north (Ebenhaeser) to south (Clanwilliam). The climate is characterised by fog and dew falls that supplement the low rainfall and leads to high humidity and relatively cool night temperatures.

Mechanical disintegration is the dominant mode of rock weathering in areas of lower rainfall, whereas chemical decomposition dominates 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:

$$N = 12.E_j / P_a$$

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 4**). In this region of the country, residual soils are generally of limited thickness and disintegration is the dominant form of weathering.

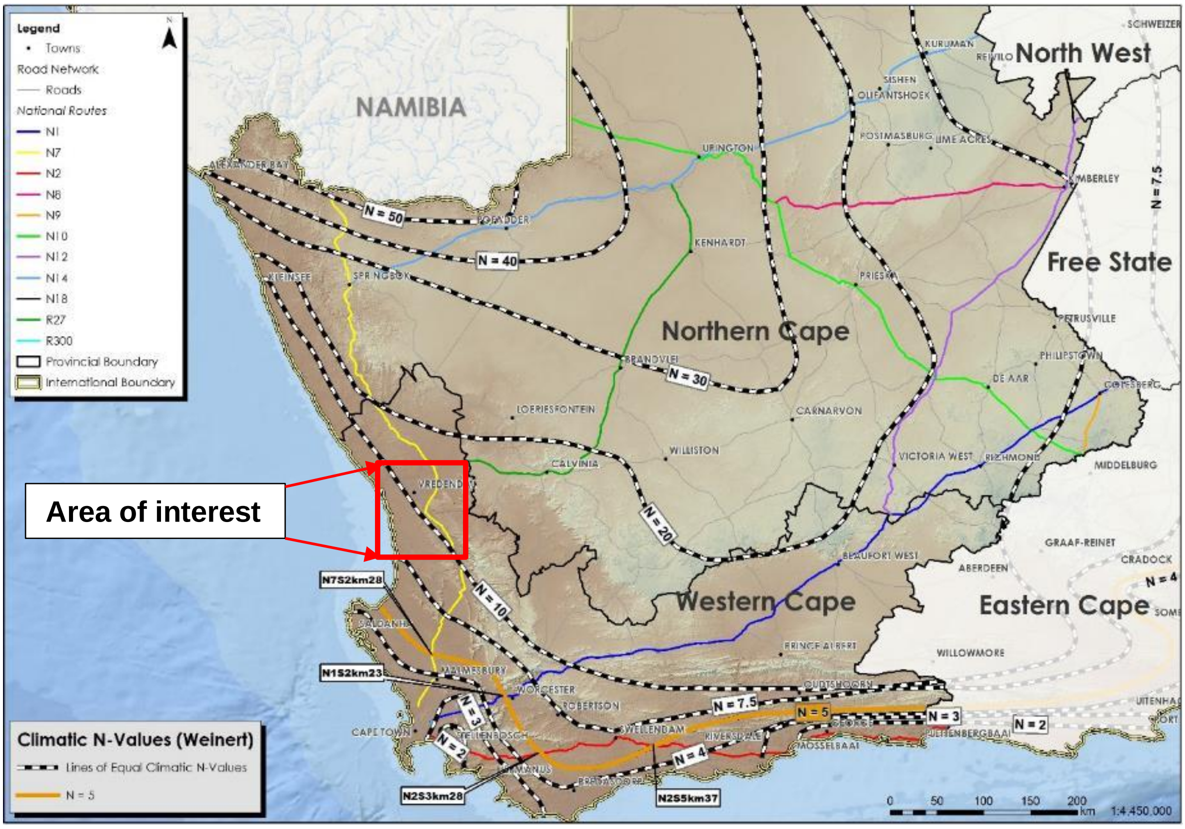

Figure 4: Climatic N-values for the affected area (modified after Weinert, 1980)

5 Investigation findings

5.1 Site description

The Jan Dissels Scheme (including both sub-options) stretches from the existing Clanwilliam Dam wall along the right bank of the dam (**Figure 1**).

The balancing dam, which is likely to be a concrete reservoir, is located at a suitable high point that is approximately 70 m from the existing Ou Kaapse Road. The Rising Main 1 Route extends for 653 m north-east, from the Clanwilliam Dam (130 m above mean sea level) to the balancing reservoir (200 m above mean sea level). The Rising Main 2 Route extends 3619 m south east, from the raised Clanwilliam Dam wall to the concrete reservoir.

The area closer to the dam comprises moderately to very steep slopes that were not accessible by TLB (**Figure 5**). This section is characterised by rock outcrop and shallow soils overlying the bedrock. Localised pockets of deeper soils might occur. Natural vegetation is typical fynbos-type collection of shrubs and succulents.

Figure 5: Rising Main 1 Route

The Rising Main 2 Route extends for 3 619 m south-east, from the existing Clanwilliam Dam to the balancing reservoir. Approximately 1 200 m of the pipeline runs through the Ramskop Nature Reserve and more than half of the proposed pipeline runs through the southern parts of the town and adjacent to the informal settlement (refer to **Figure 1**). The topography is characterised by typically moderate to gentle slopes, but also including steep rocky slopes in the vicinity of the Nature Reserve.

The remainder of the route (towards the existing Clanwilliam Dam wall) is characterised by steep rocky ridges and the vegetation generally comprises smalls shrubs or grasses (**Figure 6**).

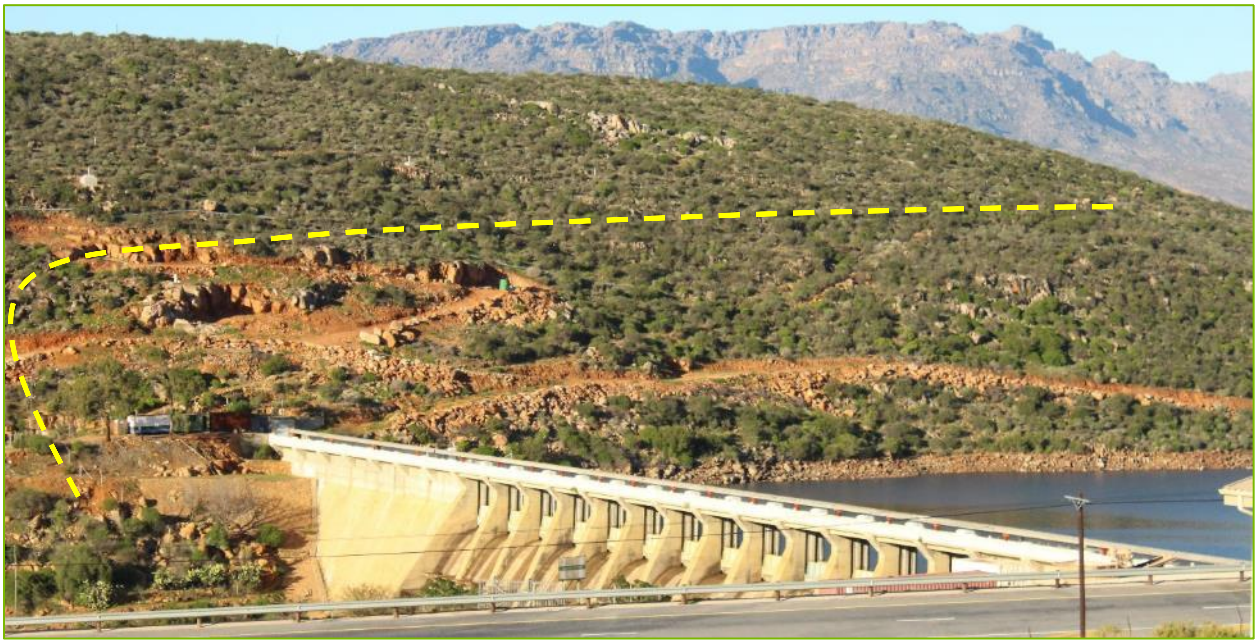

Figure 6: Rising Main 2 Route - view from left bank of Clanwilliam Dam

5.2 Geological profile

The geological profile across the entire site *generally* comprises a layer of topsoil overlying colluvium, which in turn overlies sandstone and quartzitic sandstone bedrock. The geological profile for each element is discussed in detail in Section 6.1.1 (RM 1), Section 6.2.1 (RM 2) and Section 6.3.1 (Reservoir).

It should be noted that test pits JD-TP01, JD-TP02 and JD-TP03 could not be excavated due to restricted TLB access (steep topography and rocky outcrop). In the vicinity of JD-TP17, JD-TP18 and JD-TP19 exposed cut faces on the footprint of the proposed raising of the dam were profiled.

The detailed descriptions of the soil profiles encountered in the twenty-two test pits are presented in **Appendix D** and are summarised below.

- **Topsoil** is present in two of the test pits (JD-TP05 and JD-TP22) and occurs to depths between 0.00 m and 0.20 m. The material comprises moist to very moist, brown, loose, intact, silty SAND.
- **Colluvium** is present in thirteen of the test pits (that could be excavated) and occurs from surface to a maximum depth of 1.80 m in JD-TP09. The overall consistency of this horizon is loose to medium dense, and density is expected to improve with depth.
- **Residual sand from quartzitic sandstone** is present in all the test pits, except in the area of JD-TP08 and JD-TP09. The horizon was encountered from surface at JD-TP07, JD-TP10, JD-TP13, JD-TP16 and JD-TP19 to a maximum depth of 3.00 m in JD-TP18 (termination depth of test pit). The layer generally comprises clast supported sub-rounded gravels to boulders in a

gravelly sand matrix. The overall consistency of this horizon is medium dense to dense, and density is expected to improve with depth. The gravel, cobbles and boulders comprise rounded hard rock quartzitic sandstone particles ranging in diameter from about 20 mm to 300 mm.

- **Quartzitic sandstone bedrock** is observed in existing cut slope faces in the vicinity of JD-TP17, JD-TP18 and JD-TP19, and comprises white stained pink, moderately to slightly weathered, thickly and sub-horizontally bedded, very hard rock that is very closely to moderately jointed (<20 mm). Joints are infilled with silty sand.

5.3 Laboratory test results

The results of the laboratory tests are summarised in the sections below, and the full set of results are presented in **Appendix D**.

5.3.1 Foundation Indicator

Foundation Indicator results, i.e. combined grading analyses including sieve and hydrometer analyses, as well as Atterberg constants, are summarised below in **Table 5.** The results from Labco, for quality control purposes (as discussed in Section 3.2.4), are presented in *italics*.

Table 5: Foundation indicator test results

Test pit no	Depth (m)	Soil composition				GM	Atterberg limits			LS (%)	Unified Class.	AASHTO class.
		Clay (%)	Silt (%)	Sand (%)	Gravel (%)		LL (%)	PI (%)	WPI (%)			
Colluvium												
JD-TP 04	0.0 – 0.4	4	7	87	2	1.57	0	0	0	0.0	SW-SM	A – 1 - B
JD-TP 05	0.2 – 0.7	4	8	69	19	1.79	0	0	0	0.0	SM	A – 1 - B
JD-TP 09	0.0 – 1.1	2	6	92	1	1.16	0	0	0	0.0	SP-SM	A - 3
JD-TP 12	0.0 – 0.5	2	6	90	2	1.29	0	0	0	0.0	SP-SM	A - 3
JD-TP 14	0.0 – 1.6	1	5	92	2	1.54	0	0	0	0.0	SP-SM	A – 1 - B
JD-TP 21	0.0 – 0.3	1	7	67	25	1.98	0	0	0	0.0	SW-SM	A – 1 - B
JD-TP 21	*0.0 – 0.3*	*3*	*6*	*86*	*5*	*1.43*	*0*	*0*	*0*	*0.0*	*SM*	*A – 1 - B*

Test pit no	Depth (m)	Soil composition				GM	Atterberg limits			LS (%)	Unified Class.	AASHTO class.
		Clay (%)	Silt (%)	Sand (%)	Gravel (%)		LL (%)	PI (%)	WPI (%)			
Residual soil from quartzitic sandstone												
JD-TP 06	0.15 – 1.00	4	6	48	42	2.09	0	0	0	0.0	SP-SM	A – 1 - B
JD-TP 10	0.0 – 0.7	18	18	64	0	0.84	1.9	18	3	1.9	SC-SM	A - 4
JD-TP 10	*0.0 – 0.7*	*17*	*10*	*71*	*2*	*0.90*	*0*	*SP*	*0*	*1.0*	*SM*	*A – 2 - 4*
JD-TP 11	0.1 – 0.9	2	6	69	23	1.89	0	0	0	0.0	SW-SM	A – 1 - B
JD-TP15	*0.0 – 1.2*	*2*	*2*	*76*	*20*	*1.74*	*0*	*0*	*0*	*0*	*SP*	*A – 1 - B*
JD-TP 16	0.0 – 1.4	6	5	50	38	1.84	0	0	0	0.0	SP-SM	A – 1 - B
JD-TP 22	0.6 – 1.2	6	4	61	29	2.02	0	0	0	0.0	SP-SM	A – 1 - B

Legend
GM = Grading modulus
LL = Liquid Limit
WPI = Weighted Plasticity Index
LS = Linear Shrinkage
USC = 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, 1973)

No samples of the **topsoil** were tested, as it was considered that the topsoil would be stripped from the footprint due to the organic content (i.e. presence of roots). The horizon is also very thin (up to 0.2 m) and would not be a key element in construction, although it would be stockpiled for later rehabilitation purposes.

The **colluvial** soils primarily comprise slightly silty gravelly sand; with the silt fraction of 5% to 8%, the gravel fraction ranges from 1% to up to 25% in JD-TP21 and the sand fraction varies between 67% and 92%. Clay fractions are negligible; up to 2%. Due to the negligible clay fraction the Liquid Limits (LL) as well as the Plasticity Index (PI) values are 0%. These colluvium materials are therefore considered to be non-plastic.

The **residual soils derived from quartzitic sandstone** typically occur as sub-rounded hard rock gravel, cobbles and boulders in a matrix of gravelly sand, with the exception in JD-TP10. Importantly, only the finer fraction was submitted for testing, i.e. the coarse fraction comprising cobbles and boulders, as well as the gravels, was not included in the test samples. The sand fraction ranges from 48% to 76% and the gravel fraction varies between 23% and 42%. The clay and silt fractions are commonly up to 6%. Due to the negligible clay fraction the Liquid Limits (LL) as well as the Plasticity Index (PI) values are 0%. In JD-TP10 however, the residual quartzitic sandstone comprises clay (18%), silt (14%) and sand (68%). The Liquid Limit is 1.9% (indicating soils with low plasticity), and the Linear shrinkage 1.9% i.e. very low value.

5.3.2 Compaction

Summarised compaction results are presented in **Table 6.**

Table 6: Compaction test results

Test No.	Depth (m)	OMC (%)	MDD (kg-/m3)	Swell (%)	CBR at various densities				COLTO / TRH14 Class-ification
					90(%)	93(%)	95(%)	98(%)	
Colluvium									
JD-TP 04	0.0 – 0.04	11.2	1926	0	5	6	10	14	G9
JD-TP 05	0.2 – 0.7	8.3	2170	0	13	22	32	59	G6
JD-TP 09	0.0 – 1.1	13.1	1843	0	6	8	9	12	G9
Residual soil from quartzitic sandstone									
JD-TP 10	*0.0 – 0.7*	*9.4*	*2008*	*1.13*	*4*	*7*	*9*	*14*	*G10*
JD-TP15	*0.0 – 1.2*	*10.1*	*1949*	*0*	*21*	*23*	*25*	*28*	*G7*
JD-TP 22	0.6 – 1.2	8.4	2168	0	35	21	15	9	G7

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

The **colluvium** horizon in the vicinity of Rising Main 1 and Rising Main 2 is characterised by a maximum dry density (MOD AASHTO compaction) between 1926 kg/m^3 and 1843 kg/m^3 with optimum moisture contents (OMC) of 11% to 13 %. These values correspond to a G9 material in terms of COLTO materials classification. In the area of the concrete reservoir, this horizon is characterised by a maximum dry density of 2170 kg/m^3 with an Optimum Moisture Content of 8%. These values correspond to a G6 material in terms of COLTO materials classification.

The fine fraction of the **residual soil from quartzitic sandstone** in the north western portion of Rising Main 2 possesses a maximum dry density (MOD AASHTO compaction) between 1949 kg/m^3 and 2168 kg/m^3 with Optimum Moisture Content of 10% to 8 %. These values correspond to a G7 material in terms of COLTO materials classification. In the south western area of Rising Main 2, this horizon is characterised by a maximum dry density of 2008 kg/m^3 with an Optimum Moisture Content of 9%. These values correspond to a G10 material in terms of TRH14 materials classification.

5.3.3 Shear Strength

Remoulded samples were subjected to shear box testing. The results are summarised below in **Table 7**.

Table 7: Summarised direct shear strength results

Test pit No	Material type	Unified Soil Class.	Depth (m)	Apparent Friction Angle (°)	Cohesion (c) (kPa)
Colluvium					
JD-TP 04	Silty sand	SW-SM	0.0 – 0.04	44.7	4.61
JD-TP 05	Gravelly sand	SM	0.2 – 0.7	43.5	13.0
JD-TP 09	Silty sand	SP-SM	0.0 – 1.1	42.1	1.12
Residual soil from quartzitic sandstone					
JD-TP 10	Silty, clayey sand	SC-SM	0.0 – 0.7	24.3	15.20
JD-TP 22	Gravelly sand	SP-SM	0.6 – 1.2	41.3	13.14

Shear strength consists almost wholly of internal friction and cohesion. Uniform materials are generally workable; that is, they are easily excavated and compacted. The shear strength of a material increases as the range in sizes of coarse-grained soils increases.

The **colluvium** horizon comprises a range of well-graded sands and gravelly sands (SW), poorly graded sands and gravelly sands (SP), and silty sand mixtures (SM). The cohesion for this horizon varies from 1 kPa to 13 kPa, with a minimum apparent friction angle of 42.1° and a maximum of 44.7°.

The **residual soils from quartzitic sandstone** comprise a range of poorly graded sands and gravelly sands (SP), clayey sands, sand-silt mixtures (SC) and silty sand mixtures (SM). The cohesion for this horizon varies from 13 kPa to 15 kPa, with a minimum apparent friction angle of 24.3° and a maximum of 41.3°. The relatively low shear strength encountered in JD-TP10 is associated with the relatively high clay content.

5.3.4 Chemical (pH & conductivity)

Representative soil samples of different soil horizons encountered on site were subjected to chemical (pH and conductivity) tests.

The pH and conductivity of soil is generally determined to provide an indication of the potential corrosiveness of the soil. The rate of corrosion also occurs differently according to the pH value of the soil. The higher pH in the soil indicates an alkaline condition while the lower pH of the soil indicates an acidic condition. According to Powell et. al, (1995) the corrosion rate increases with decreasing pH value. The acidic environment with pH lower than 6 is more corrosive compared to pH from 6–8 or alkaline pH higher than 8 (Bradford, 1993).

Based on Evans' guideline (1977) a soil pH less than 6 indicates serious corrosion potential. A pH lower than 4.5 can therefore cause rapid metal corrosion and presents serious risks to common construction materials, including some stainless-steel grades.

Duligal (1996) provides guidelines for evaluation of the conductivity of soil, as given in **Table 8**.

Table 8: Guidelines for evaluation of the conductivity of soil, (Duligal, 1996)

Soil conductivity (mS/m)	Soil resistivity (Ohm.cm)	Corrosiveness 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 are summarised in **Table 9**.

Table 9: Chemical test results

Test pit No	Depth (m)	pH	Conductivity (mS/m)
Colluvium			
JD-TP 04	0.0 – 0.04	4.2	0.008
JD-TP 05	0.2 – 0.7	4.5	0.011
JD-TP 09	0.0 – 1.1	5.1	0.022
Residual quartzitic sandstone			
JD-TP 10	0.0 – 0.7	5.8	0.002
JD-TP 22	0.6 – 1.2	4.3	0.012

From the results in **Table 9** and the guidelines in **Table 8** it is evident that:

- The **colluvium** is not generally corrosive according to the low conductivity values that range between 0.008 and 0.022 mS/m. In terms of the guideline by Evans (1977), in the area around JD-TP04 and JD-TP05 where the results indicate pH values of 4.2 and 4.5 respectively, the material is classified as very corrosive. A pH lower than 4.5 can therefore cause rapid metal corrosion and presents serious risks to common construction materials, including some stainless-steel grades.
- The **residual soils** from quartzitic sandstone have pH values ranging between 4.3 around JD-TP22 and 5.8 around JD-TP10, indicating the soil to be very corrosive. On the contrary, very low conductivity values around both areas are indicating that the horizon is generally non-corrosive.

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

Soil electrical 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, as found in all stations, should have higher soluble salts content and therefore high electrical conductivity.

This is not apparent in the laboratory results, where conductivity values are generally lower than 10 mS/m and therefore indicates the soils are non-corrosive.

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

5.4 Field test results

5.4.1 Soil electrical resistivity

A total of eight locations were tested; six test locations were determined to represent typical ground conditions, while two additional tests were conducted to verify results. These test locations are shown in **Figure 7**.

Figure 7: Location of field resistivity tests

The test locations were set out to represent certain ground types within the geological profile as shown in **Figure 8**. The ground types represented are as follows:

- Residual quartzitic sandstone
- Colluvium
- Hard rock quartzitic sandstone boulders

Figure 8: Representative ground types along test locations

The detailed soil resistivity report is presented in **Appendix E** and a summary of the results is provided in Table 10 below. Results are given in Ohms per meter (Ω.m).

Table 10: Soil Resistivity Test Results in Ω.m for the Jan Dissels Scheme Test Locations

Probe Spacing	LOC1 / Residual quartzitic sandstone		LOC2 / Residual quartzitic sandstone		LOC3 / Residual quartzitic sandstone		LOC4 / Quartzitic sandstone outcrop overlying colluvium	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
1	181	269	10	8	10	9	653	571
2	78	85	16	14	22	19	196	150
3	57	80	21	18	22	27	95	84
5	50	62	19	20	36	38	88	89
Trend	Decreasing		Increasing		Increasing		Decreasing	
1	3142	2218	1483	1521	1521	2708	487	360
2	2200	2373	557	970	1405	1571	200	265
3	2175	1915	447	603	1943	1269	114	188
5	1458	842	519	519	1847	1901	118	90
Trend	Decreasing		Decreasing		Increasing		Decreasing	

For each location the average of the two perpendicular test measurements at the 3 m spacing is shown in Figure 8. Figure 9 shows locations in order from left to right, as they appear in Figure 8, following the proposed pipeline route.

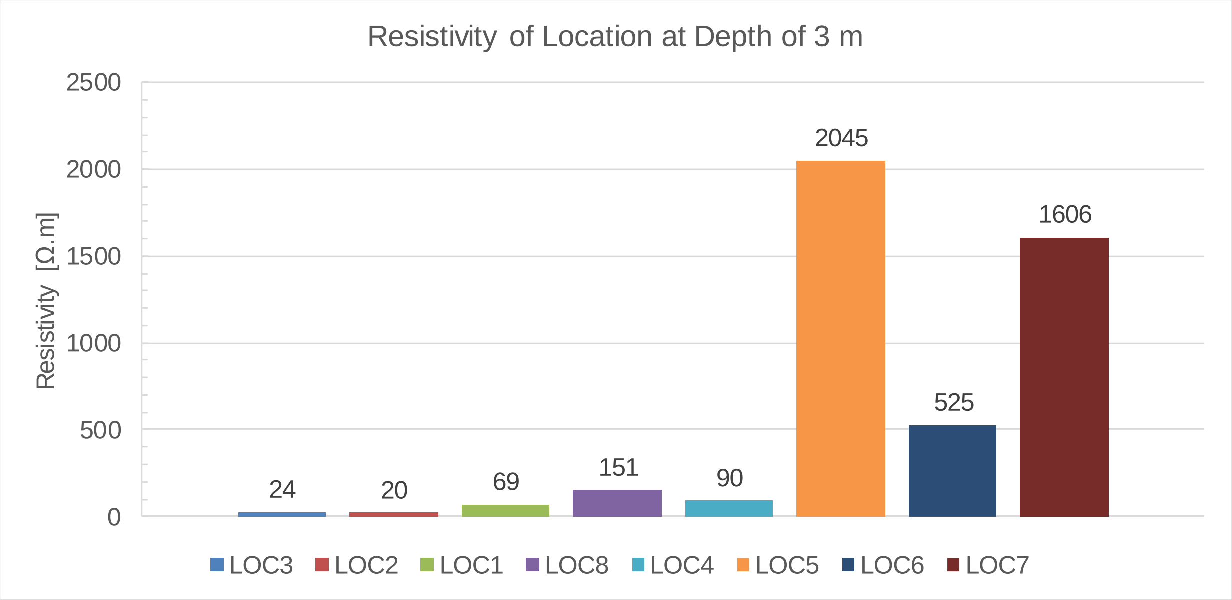

Figure 9: Measured Soil Resistivity at 3 m Depth

According to the results, resistivity readings along all locations range from 20 to 2045 Ω.m. It is apparent that resistivity values for the residual quartzitic sandstone range from 24 to 69 Ω.m, with an overall increasing trend. Resistivity values for the quartzitic sandstone outcrop overlying colluvium range from 90 to 2045 Ω.m, with a decreasing trend. The quartzitic sandstone boulders obtained readings that range from 525 to 1606 Ω.m.

However, the above observations are only based on the electrical measurement and the materials are further classified according to the soil electrical resistivity classification by Roberge, (2008). The adopted corrosion severity ratings are given in **Table 11** and discussed in detail under the respective elements in Section 6.1 (RM1), Section 6.2 (RM2) and Section 6.2 (Reservoir).

Table 11: Corrosiveness Ratings Based on Soil Resistivity, after Roberge, (2008)

Soil Resistivity (Ω.m)	Corrosivity Rating
> 200	Essentially noncorrosive
100 to 200	Mildly corrosive
50 to 100	Moderately corrosive
30 to 50	Corrosive
10 to 30	Highly corrosive
<10	Extremely corrosive

5.4.2 Dynamic cone penetration (DCP)

The DCP tests were conducted from surface at JD-TP01 and JD-TP02. No DCP testing could be conducted in the other test pits where colluvium, residual quartzitic sandstone boulders and hard rock quartzitic sandstone outcrop were present. According to the results given in **Table 12**, the consistency of the materials adjacent to the dam (where the pump station is located) range from medium dense to very dense.

Table 12: DCP test results

Test pit No:	Depth where <5 PR (mm/blow)	Depth where 5 < PR < 15 (mm/blow)	Depth where 15 < PR < 30 (mm/blow)	Depth where 30< PR < 75 (mm/blow)	Depth where PR > 75 (mm/blow)
JD-TP1	0.28 – 0.32	0.20 – 0.28	0.00 – 0.20	-	-
JD-TP2	-	0.12 – 0 28	0.00 – 0.12	-	-

*PR = Penetration rate

6 Geotechnical considerations

Each of the respective elements of the Jan Dissels Scheme is discussed separately in terms of the various engineering geological / geotechnical implications and considerations.

6.1 Rising Main 1 – directly from dam basin

This option involves the construction of an approximately 650 m long, 500 mm diameter rising main pipeline from the 600 kW pump station to the balancing reservoir The pump station could be a floating inlet or could be on the shore of the raised Clanwilliam Dam (above the 1:100 year flood line).

6.1.1 Geological profile

Three test pits were excavated (numbered JD-TP04, JD-TP20 and JD-TP21), along the alignment of Rising Main 1; primarily to confirm the geological profile. Three test pit locations, namely JD-TP01, JD-TP02 and JD-TP03, were not accessible with the TLB and could not be excavated. The test pit positions along the pipeline route are shown in **Figure 10**.

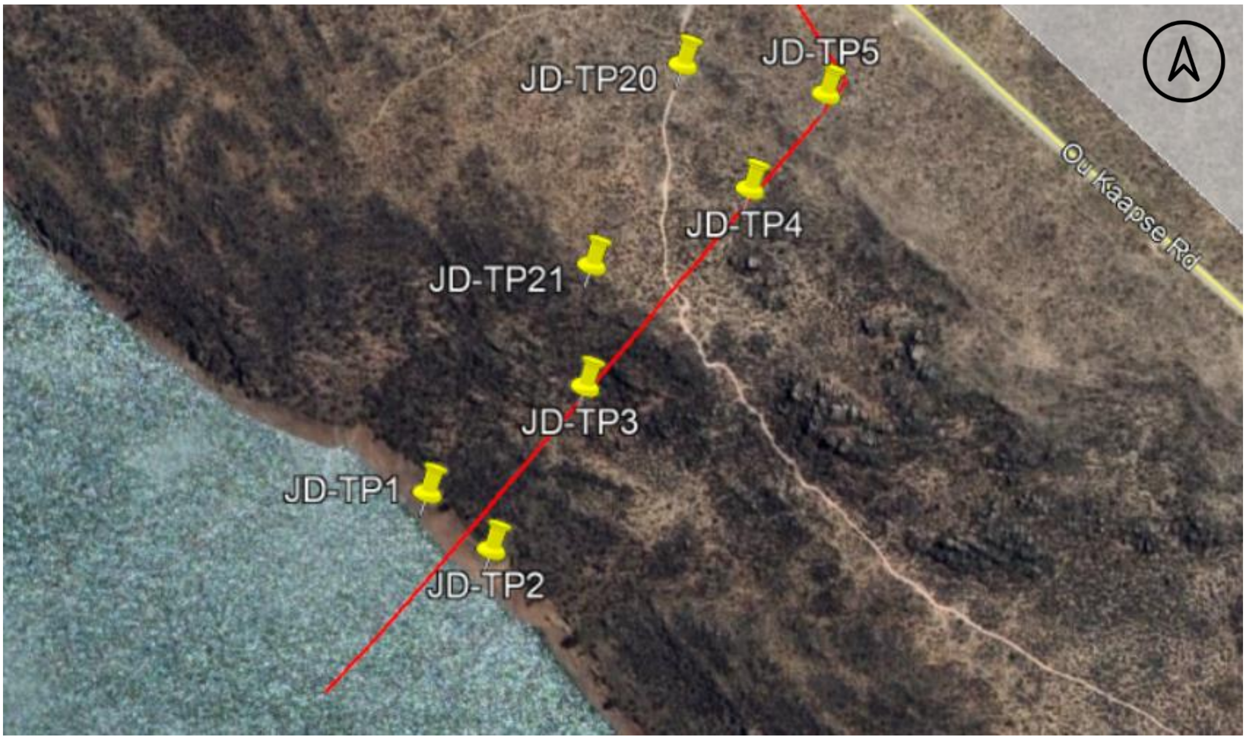

Figure 10: Test pit positions along Rising Main 1

Geological profiles for Rising Main 1 are summarised in **Table 13**.

Table 13: Rising Main 1: Summarised geological test pit profiles (depths in m)

TP no	Colluvium; very loose to dense, gravelly and silty sand	Residual quartzitic sandstone; gravels / cobbles in sand matrix, overall very loose to loose.	Quartzitic sandstone; Moderately to slightly weathered, coarse grained, bedded, hard rock.
JD-TP03	Inaccessible with the TLB, sandstone boulders outcrop, shallow bedrock expected		
JD-TP04	0.00 – 0.40	0.40 – 1.00	
JD-TP20	0.00 – 0.20		0.20 – 0.50
JD-TP21	0.00 – 0.30	0.30 – 0.80	

The typical soil profile along Rising Main 1 comprises;

- Colluvium.
- Residual quartzitic sandstone.
- Quartzitic sandstone bedrock.

Colluvium is encountered in all three excavated test pits along the pipeline route. The material comprises moist to very moist, brown to dark brown very loose to dense, gravelly sand. In test pit JD-TP20 this horizon is 0.20 m thick and 0.40 m in JD-TP04 (average thickness of 0.30 m) encountered towards the south-east section of the pipeline route.

The **residual soil from quartzitic sandstone** occurs in JD-TP04 and JD-TP21 along the route of Rising Main 1, but was not evident in JD-TP20, which is located slightly north of the pipeline route. Essentially, this material comprises silty sand (matrix) with a coarser fraction comprising sub-rounded to sub-angular gravels and occasional boulders. The overall consistency varies from very loose to loose. Refusal on hard rock quartzitic sandstone boulders was recorded at 1 m maximum depth and 0.8 m minimum depth along the pipeline route.

Hard rock quartzitic sandstone was intersected at 0.20 m in JD-TP20. The strata comprise off-white and orange, moderately to slightly weathered, coarse grained, bedded, hard rock. No joint sets were observed in this layer. Scattered hard rock quartzitic sandstone is present as outcrop along the entire Rising Main 1 route. Steep cliffs are present towards the south east of the pipeline route, towards the dam.

6.1.2 Founding considerations

Bedrock was intersected at shallow depths along the Rising Main 1 pipeline route. Extensive excavation (as for a buried pipeline / trench) could however be avoided, if the pipeline is to be constructed above natural ground level (NGL). Should the latter be considered, shallow foundations would be needed for the pipeline pedestals. Adequate bearing capacity would be obtained from the hard rock quartzitic sandstone.

6.1.3 Excavation considerations

In case of a buried pipeline / trench, the test pit profiles have been used to estimate the general depths of the anticipated excavation classes (soft and hard) at the site, which is presented in **Table 14**.

Table 14: Rising Main 1: Average depth of anticipated excavation classes

Test pit	Average depth of excavation class (m)	
	Soft	Hard
JD-TP04	0.00 – 1.00	1.00+
JD-TP20	0.00 – 0.50	0.50+
JD-TP21	0.00 – 0.80	0.80+

The overlying colluvium horizon occurs in “pockets” of variable depth and can generally be classified as “Soft Excavation” in terms of SANS 1200D: Earthworks, (SANS, 1988). The quartzitic sandstone bedrock will be classified as “Hard Excavation” in terms of SANS 1200D.

6.1.4 Corrosiveness of material

Soil electrical resistivity tests have been conducted in the area of the hard rock quartzitic sandstone boulders (JD-TP01, JD-TP02 and JD-TP03) towards the south-west, and on the colluvium (JD-TP04 and JD-TP05) towards the north-east.

According to the soil electricity resistivity results in combination with the chemical results (**Table 15: Corrosiveness along Rising Main 1 route**), the colluvium and quartzitic sandstone outcrop are classified as essentially non-corrosive, according to Roberge, (2008).

Table 15: Corrosiveness along Rising Main 1 route

Hole No	Depth (m)	Material Description	pH	Conductivity mS/m	Soil Electrical Resistivity (Ω.m)	Classification (after Roberge, 2008)
JD-TP03	Hard rock quartzitic sandstone outcrop		-	-	525 - 1606	essentially noncorrosive
JD-TP04	0.00-0.40	Sand: Colluvium	4.2	33	2045	essentially noncorrosive

Based on Evans’ guideline (1977) a soil pH less than 6 indicates serious corrosion potential. A pH lower than 4.5 (as recorded within the colluvium around JD-TP04 and JD-TP05 towards the north-east) can therefore cause rapid metal corrosion and presents serious risks to common construction materials, including some stainless-steel grades.

However, corrosion is an electro-chemical process whereby metals are changed, and electrical energy is released. The conductivity of the soil therefore has a profound influence on the rate of corrosion of buried metallic objects.

6.2 Rising Main 2 – from dam wall

6.2.1 Geological profile

Thirteen test pits were excavated (JD-TP08 to JD-TP19 and JD-TP22) primarily to confirm founding conditions along the route of Rising Main 2, which starts downstream of the raised dam wall. The test pit positions along the pipeline route are shown in **Figure 11**.

Figure 11: Test pit positions along Rising Main 2

Geological profiles within the test pits for Rising Main 2 are summarised in **Table 16**.

Table 16: Rising Main 2: Summarised geological test pit profiles (depths in m)

TP No	Colluvium; very loose to medium dense, gravelly sand	Residual quartzitic sandstone; Gravels / cobbles in sand matrix, overall, very loose to loose	Residual quartzitic sandstone; moist, loose to medium dense, clayey silty sand	Residual quartzitic sandstone; brownish red, dense, stratified, gravelly sand	Quartzitic sandstone; moderate to highly weathered, excavated as angular boulders and cobbles, medium hard rock	Quartzitic sandstone; moderately to slightly weathered, thickly and sub-horizontally bedded, very closely to moderately jointed, very hard rock
JD-TP08	0.00 – 0.30					
JD-TP09	0.00 – 1.80					
JD-TP10			0.00 – 0.70			
JD-TP11	0.00 – 0.10	0.10 – 0.90			0.90 – 1.40	

TP No	Colluvium; very loose to medium dense, gravelly sand	Residual quartzitic sandstone; Gravels / cobbles in sand matrix, overall, very loose to loose	Residual quartzitic sandstone; moist, loose to medium dense, clayey silty sand	Residual quartzitic sandstone; brownish red, dense, stratified, gravelly sand	Quartzitic sandstone; moderate to highly weathered, excavated as angular boulders and cobbles, medium hard rock	Quartzitic sandstone; moderately to slightly weathered, thickly and sub-horizontally bedded, very closely to moderately jointed, very hard rock
JD-TP12	0.00 – 0.50	0.50 – 2.30				
JD-TP13			0.00 – 1.10		1.10 – 1.30	
JD-TP14	0.00 – 1.60		1.60 – 2.10			
JD-TP15	0.00 – 0.70			0.70 – 1.20		
JD-TP16		0.00 – 1.70				
JD-TP17	0.00 – 0.40					0.40 – 5.00
JD-TP18	0.00 – 0.35					0.35 – 3.00
JD-TP19						0.00 – 2.00
JD-TP22	0.00 – 0.60	0.60 – 1.20				

The typical soil profile within the Rising Main 2 test pits comprises the following:

- Colluvium.
- Residual quartzitic sandstone sand with gravels and occasional boulders.
- Residual quartzitic sandstone (clayey silty sand).
- Hard rock, horizontally bedded, quartzitic sandstone bedrock.

Colluvium is encountered along the entire pipeline route. The material comprises moist to very moist, brown to dark brown very loose to dense, gravelly sand. The thickness of this layer ranges from 0.10 m in test pit JD-TP11 to 1.80 m in JD-TP09.

The **residual quartzitic sandstone sand with gravels and occasional boulders** occurs in three of the test pits. Thickness of the soil stratum varied between 0.60 m in JD-TP22 and at least 1.80 m in JD-TP12. Essentially, this material comprises silty sand (matrix) with a coarser fraction comprising sub-rounded to sub-angular gravels and occasional boulders. The overall consistency varies from loose in JD-TP12, very loose in JD-TP16 and loose to medium dense in JD-TP22. Refusal on hard rock quartzitic sandstone boulders occurs at 2.3 m maximum depth and 1.2 m minimum depth along the pipeline route.

The **soil from quartzitic sandstone** comprises very moist, dark brown mottled red and orange, medium dense to dense, intact, ferruginized clayey silty sand. The layer was intersected at surface in JD-TP10 and JD-TP13 and at a depth of 1.6 m in JD-TP14.

Hard to very hard rock quartzitic sandstone is observed in the vicinity of JD-TP17, JD-TP18 and JD-TP19 in cut faces at the existing Clanwilliam Dam wall. These slopes are characterized by the large blocks up to 2 m, slightly to moderately weathered along discontinuities, very hard rock, quartzitic sandstone. The rock is off-white stained pink, thickly and sub-horizontally bedded, very closely to moderately jointed. Joints are <20 mm open and in-filled with silty sand.

6.2.2 Founding considerations

It is understood that the Rising Main 2 pipeline will be buried below the natural ground level. Hard rock quartzitic sandstone was always found shallower than 3 m depth in all the test pits along the pipeline route.

6.2.3 Excavation considerations

The test pit profiles have been used to estimate the general depths of the anticipated excavation classes (soft and hard) at the site, which are presented in **Table 17**.

Table 17: Rising Main 2: Average depth of anticipated excavation classes

Test pit	Average depth of excavation class (m)	
	Soft	Hard
JD-TP08	0.30	0.30+
JD-TP09	1.80	1.80+
JD-TP10	0.70	0.70+
JD-TP11	1.40	1.40+
JD-TP12	2.30	2.30+
JD-TP13	1.10	1.10+
JD-TP14	2.10	2.10+
JD-TP15	1.20	1.20+
JD-TP16	1.70	1.70+
JD-TP17	0.40	0.40+
JD-TP18	0.35	0.35+
JD-TP19		0.00+
JD-TP22	1.20	1.20+

Hard to very hard rock quartzitic sandstone scattered outcrop is evident along the entire route. The overlying colluvium horizon occurs in "pockets" of variable depth and can generally be classified as "Soft Excavation" in terms of SANS 1200D: Earthworks, (SANS, 1988). The quartzitic sandstone bedrock will be classified as "Hard Excavation" in terms of SANS 1200D.

6.2.4 Corrosiveness of material

Soil electrical resistivity has been conducted in the residual quartzitic sandstone towards the south east of the Rising Main 2 pipeline route (JD-TP10 and JD-TP11). According to the resistivity results in combination with the chemical results *around this particular area* (**Table 18**), the residual soil from quartzitic sandstone ranges from moderately corrosive to highly corrosive, according to Roberge, (2008).

Table 18: Corrosiveness along Rising Main 2 pipeline route

Hole No	Depth (m)	Material Description	pH	Conductivity mS/m	Soil Electrical Resistivity (Ω.m)	Classification
JD-TP10	0.0 – 0.7	clayey silty SAND. Residual sandstone	5.8	0.0 – 0.7	20-24	highly corrosive
JD-TP11	-	-	-	-	69	moderately corrosive

The residual quartzitic sandstone in JD-TP10, located along the RM2 pipeline route, has a pH value of 5.8. This indicates serious corrosion potential, according to the Evans' guideline, (1977).

Corrosiveness values for the colluvium horizon, extrapolated from adjacent locations, indicate that this horizon ranges from essentially non-corrosive to moderately corrosive.

6.2.5 Stability of cut slopes

Construction activities will result in temporary cut slopes, for instance for the pipeline route. These excavated faces within the *soil horizons* might be as deep as 2.30 m along the pipeline route.

The gravelly sand stratum of residual quartzitic sandstone is of particular concern in terms of the stability of cut slopes. Where the cut slopes intersect this horizon, there is a likelihood that ravelling, and spalling will occur. 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 and boulders 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.

All slopes must be cut to safe angles, and/or shored as appropriate. Particular attention must be paid to the horizon described above. It is essential that the safe slope angles for these cut faces be verified by a suitably qualified and experienced geotechnical practitioner.

6.3 Reservoir site

6.3.1 Geological profile

Test pits were excavated within the reservoir area, primarily to confirm founding conditions. Three test pits were excavated (numbered JD-TP05, JD-TP06 and JD-TP07), on the footprint of the reservoir (**Figure 12)**.

Figure 12: Test pit positions on the reservoir footprint

Geological profiles within the test pits for the reservoir are summarised in **Table 19**.

Table 19: Reservoir area: Summarised geological test pit profiles (depths in m)

TP no	Topsoil; loose, silty sand	Colluvium; medium dense to dense, gravelly sand	Gravels / cobbles in sand matrix, Overall, very dense to medium dense. Residual quartzitic sandstone	Hard rock quartzitic sandstone bedrock
JD-TP05	0 – 0.20	0.20 – 0.70	0.70 – 1.10	1.10+
JD-TP06		0.00 – 0.15	0.15 – 1.00	1.00+
JD-TP07			0.00 – 0.30	0.30+

The typical soil profile within the reservoir area comprises the following:

- Topsoil.
- Colluvium.
- Residual soil from quartzitic sandstone.

The upper **topsoil** was recorded in JD-TP05 but observed in places around the entire area of the reservoir. These soils are described as moist to very moist, brown, loose, intact, silty sand. Roots, i.e. organic material, are typically present in the topsoil. The thickness of the layer in JD-TP05 is 0.20 m.

Colluvium is encountered in JD-TP06 and JD-TP05 within the reservoir footprint. The material comprises moist to very moist, brown, loose to dense, gravelly sand. In test pit JD-TP06 this horizon is 0.15 m thick and relatively thicker, 0.50 m, in JD-TP05.

The **residual soil from quartzitic sandstone** occurs in all three test pits along the reservoir footprint. Thickness varied from 0.30 m towards the north-west (JD-TP07) to 0.40 m towards the south-west (JD-TP05). A maximum thickness of 0.85 m was encountered towards the eastern side of the reservoir footprint in JD-TP06. Essentially, this material comprises slightly silty, gravelly sand (matrix) with a coarser fraction comprising sub-rounded to sub-angular gravels and occasional boulders. The overall consistency varies within the three test pits; medium dense to very dense in JD-TP05, loose to medium dense in JD-TP06 and very loose in JD-TP07. All three test pits refused on medium to hard rock quartzitic sandstone bedrock.

Hard rock quartzitic sandstone was intersected between depths 0.30 m and 1.10 m on the reservoir footprint. Hard rock quartzitic sandstone is present as outcrop in the reservoir area as well as along the route of Rising Main 1.

6.3.2 Founding considerations

A reinforced concrete slab foundation is a common approach for small reservoirs and is proposed for the Jan Dissels Scheme. Relatively small differences in soil settlement under the slab can cause initiating and developing of cracks in the slab, so the concrete slab should ideally be founded on competent material. Adequate bearing capacity may be obtained from the hard rock quartzitic sandstone that was intersected at a maximum depth of 1.10 m along the perimeter of the reservoir. Bedrock that will provide the desired bearing capacity is therefore found at shallow depths on the footprint.

Alternatively, a compacted backfill below the structure could be considered. However, considering the shallow bedrock, there is little reason to favour this approach, which would require importing of suitable backfill material.

6.3.3 Excavation considerations

Excavation classification for earthworks has been evaluated according to the South African Bureau of Standards standardised excavation classification for earthworks; SANS 1200D. In terms of this classification and the in-situ soil/rock consistencies as profiled, the relationships given below are generally applicable:

- **Soft excavation conditions:** Material excavated with excavator up to refusal depth
- **Hard excavation conditions:** Any material deeper than soft excavation material (commonly quartzitic sandstone bedrock)

The test pit profiles have been used to estimate the general depths of the anticipated excavation classes (soft and hard) at the site, which is presented in **Table 20**.

Table 20: Concrete reservoir: Average depths of anticipated excavation classes

Test pit	Average depth of excavation class (m)	
	Soft	Hard
JD-TP05	0.70	0.70+
JD-TP06	0.15	0.15+
JD-TP07		0.30+

The overlying colluvium horizon occurs in "pockets" of variable depth and can generally be classified as "Soft Excavation" in terms of SANS 1200D: Earthworks, (SANS, 1988). The hard rock quartzitic sandstone will be classified as "Hard Excavation" in terms of SANS 1200D.

The hard rock quartzitic sandstone occurs at irregular depths. Blasting of hard rock will be required for reservoir foundation to ensure a level foundation on the bedrock.

6.3.4 Corrosiveness of material

Soil electrical resistivity tests have been conducted in the area of JD-TP05 and JD-TP06 at the balancing reservoir site. According to the resistivity results, in combination with the chemical results (**Table 21**), the colluvium around JD-TP05 is classified as moderately corrosive, while the area around JD-TP06 is classified as mildly corrosive, according to Roberge, (2008).

Table 21: Balancing reservoir: Corrosiveness of material

Hole No	Depth (m)	Material Description	pH	Conductivity mS/m	Soil Electrical Resistivity (Ω.m)	Classification (after Roberge, 2008)
JD-TP05	0.20-0.70	Gravelly sand: Colluvium	4.5	0.011	90	moderately corrosive
JD-TP06	-	-	-	-	151	mildly corrosive

The colluvium stratum in the vicinity of the concrete reservoir site has a pH value of 4.5. This horizon is classified as corrosive and according to the Evans' guideline (1977) a soil pH lower than 4.5 can cause rapid metal corrosion and presents serious risks to common construction materials, including some stainless-steel grades and concrete.

6.3.5 Slope stability

The area is essentially flat / gently sloping, and construction of the concrete reservoir does not require deep cuts, i.e. < 1.5 m deep. Therefore, no slope stability issues are foreseen relating to the construction of the balancing reservoir.

6.4 Groundwater

Groundwater seepage was not encountered in any of the test pits excavated on site. It should however be noted that the scheme is located in close proximity to the existing Clanwilliam Dam. During the time that fieldwork was conducted (July 2020), a rise in water level in the dam increased from 30% to 70% within a week.

Therefore, groundwater seepage is possible to occur within foundation and service trench excavations at shallower depth during a more profound rainy season.

If groundwater is encountered during construction, proper sub-surface drainage, including damp proofing, should form part of the permanent works.

6.5 Suitability of excavated material for use as selected backfill

To date, there has been no geotechnical focus on wider sources of construction materials, other than the *in-situ* materials encountered within the corridor investigated. Current investigations did not actively target the proving of potential hard rock sources that might be crushed to produce coarse aggregate. However, the laboratory test results, and the results of the fieldwork were used to evaluate the suitability of the various on-site soils/rocks for use in the backfill (selected fill and main fill) of the trench excavation for the pipeline, and as possible bedding material (selected granular material). Based on the USCS classification the colluvium encountered on site is predominantly categorized as poorly graded sand (SP) to silty sand (SM). The residual quartzitic sandstone is categorized as clayey sand (SC) or clay with high plasticity (CH) and well graded sand (SW) based on USCS classification.

Table 22 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 22: Bedding material type requirements

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 considerations in **Table 22** should be noted regarding the re-use of *in situ* material.

Table 23: Assumed material re-use of the in-situ material (Standards South Africa, 1988: SANS 1200LB and 1200DB).

Material origin	Material Classification	Plasticity Index Range	Grading Modulus Range	Percent clay	Assumed re-use
Colluvium	SW, SM, SP A-3, A-1-B	0	1.16 – 1.98	1% - 4%	Mainly suitable as bedding cradle and selected fill blanket, i.e. SC1 and SC2 bedding material types.
Residual Quartzitic Sandstone	SP, SM, SW and occasionally SC A-4, A-1-B, A-2-4	Mainly 0, occasional 18	0.84 – 2.09	18%	Not suitable as bedding and backfill material

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 than 10% of rock or hard fragments that are retained on a 50 mm aperture sieve. 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 colluvium material is classified as G9 and residual quartzitic sandstone is classified as G10 quality according to the TRH 14 guideline (Guidelines for Road Construction Materials, CSIR), which may be suitable for engineered fill layers of low stiffness *only*. In addition, the colluvium material is classified as G6 and residual quartzitic sandstone classified as G7 quality according to COLTO classification and is suitable for the construction of engineered fills of moderate stiffness and selected or subgrade layers. Such material may be suitable for construction of the concrete reservoir and possible pedestal foundations of Rising Main 1, unless the pedestals can all be founded on bedrock.

6.6 Additional sources for construction material

It is highly unlikely that a new hard rock quarry site would be developed as a source of crushed stone. The area close to Clanwilliam Dam is characterised by outcrop of hard rock quartzitic sandstone and an old quarry is located close to the left flank of the Dam. This source was used for the Clanwilliam Dam and is earmarked for the imminent dam raising. This rock has been proved to be suitable for the manufacture of course aggregate.

In addition, alkali–aggregate reaction (AAR) has been recorded in aggregates used for the dam construction, which may cause concrete deterioration over time. All aggregates must be checked in this regard and appropriate mix designs should be used.

7 Conclusions and recommendations

7.1 Excavation considerations

To ensure effective excavation advance within the boulder colluvium and soft to medium hard rock, quartzitic sandstone, it is recommended that excavation by means of power tools, such as pneumatic rock breaker attached to a track excavator for instance, should be considered. Blasting is recommended within the hard rock quartzitic sandstone.

If the **Rising Main 1** and the north western part of **Rising Main 2**, which are in relatively close proximity to the Clanwilliam Dam, are considered to be a buried pipeline, blasting may be required. It should be noted that blast vibration may cause damage to the dam structure. If possible, blasting should be avoided and must be controlled if it is implemented.

7.2 Slope stability and lateral support

Major sidewall collapse occurred in the colluvium layer, which often led to the termination of the test pit excavations. In addition, sidewall stability can worsen drastically if water is to be encountered in excavations, albeit in the form of a perched water table or poor surface water run-off, which may accidently be draining into excavations during construction. Therefore, excavation sidewalls being formed through the boulder colluvium and deeper than 1.50 m (possibly for **Rising Main 2**), must either be battered back to safe slopes or shored. This is essential to ensure safe working conditions for workers in excavations.

No deep excavations (>1.5 m) are foreseen for the **reservoir**. Thus, complex lateral support systems are therefore not expected or required for this structure.

7.3 Soil corrosiveness

The soils in the area of the **reservoir** should be considered mildly corrosive. The material towards the south east of **Rising Main 2** ranges from moderately to highly corrosive for buried steel elements. Therefore, special consideration should be given in the design regarding the deterioration of buried steel and concrete structures in these soils.

7.4 Foundations

All foundation excavations of possible pedestals for Rising Main 1, as well as for the foundation of the reservoir, should be inspected by an experienced geotechnical engineer or engineering geologist prior to placing of concrete, to ensure that the correct 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 excavation of the foundation for these structures.

7.5 Additional Investigations

Test pits could not be excavated for the pump station due to access constraints. The geotechnical conditions for the pump station have therefore not been investigated in sufficient detail. It is recommended that follow-up geotechnical investigations be conducted, specifically where insufficient data was obtained for the pump station. Follow-up investigations would also address aspects such as confirmation of the geological continuity (laterally and with depth) across the site. Any additional design optimisations would also require that appropriate geological and geotechnical investigations are carried out.

In addition, the low soil pH value as found in all samples suggests corrosive conditions, yet the lab results yielded conductivity values which are generally lower than 10 mS/m and therefore classified as non-corrosive. It is therefore recommended that additional chemical testing be conducted to confirm the corrosiveness of the soils.

8 References

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9 Limitations of report

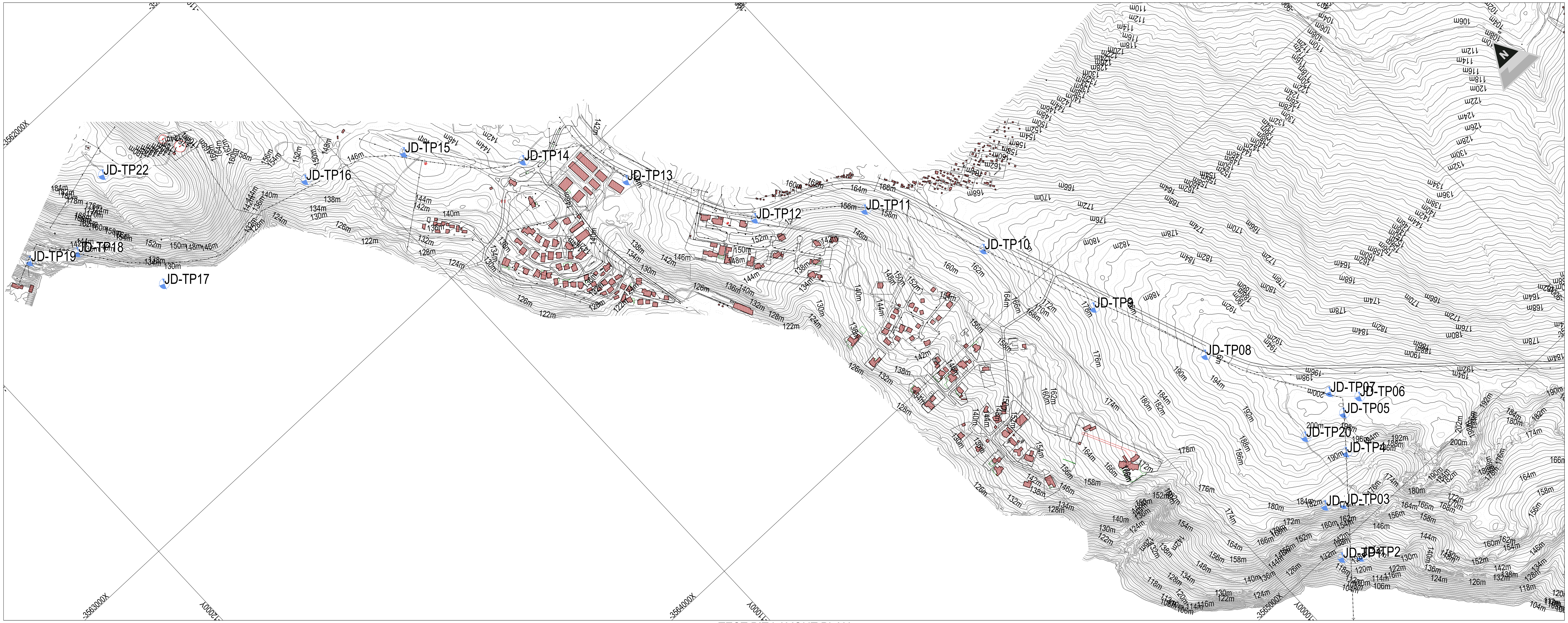
1. Aurecon Ground Engineering has prepared this report for use by Aurecon design colleagues as well as our Client, Department of Water and Sanitation (DWS). The report has not been prepared for use by parties other than the Client, and the Client's respective consulting advisors.
2. There are always 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 Aurecon 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 Aurecon 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.

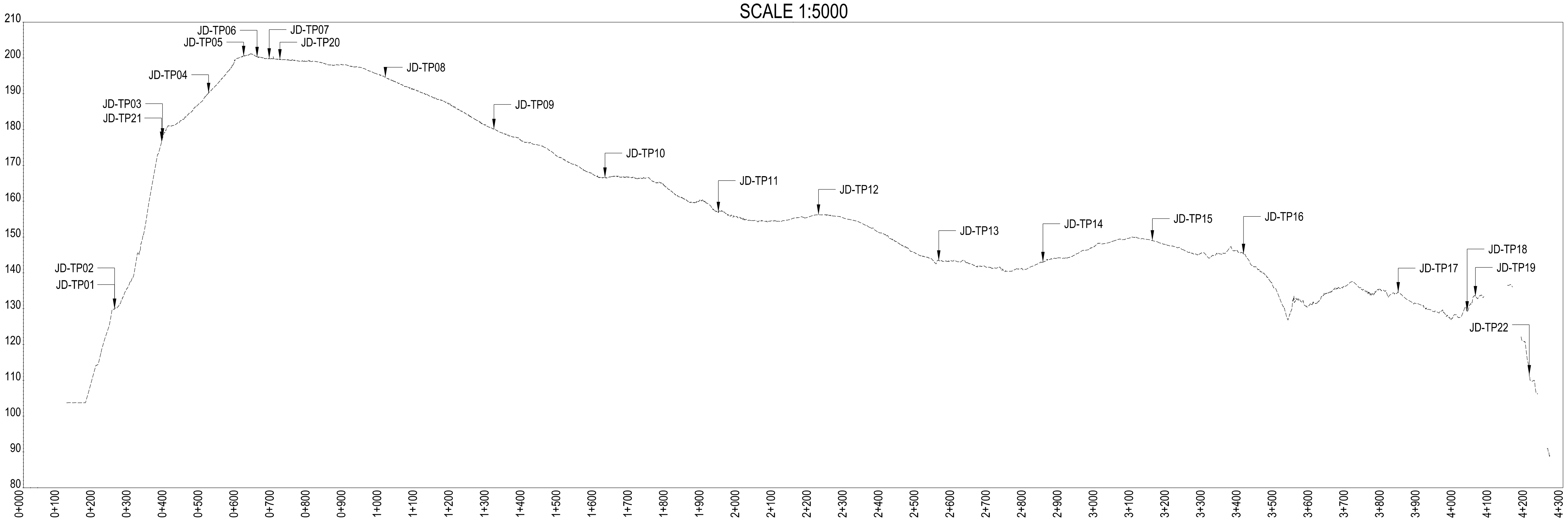
6. The investigation logs represent the subsurface conditions at the specific test locations only. Boundaries between zones on the logs are not often distinct, but rather are transitional and have been interpreted. The soil / rock descriptions in this report are based on commonly accepted methods of classification and identification employed in geotechnical practice, as stated. Classification and identification of soil involves judgement, and Aurecon 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 Aurecon 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



TEST PIT LAYOUT PLAN
SCALE 1:5000



50 0 100 200m
SCALE 1:5000

ZUTARI
IMPACT. ENGINEERED.

CLIENT	DISCLAIMER	REV	DATE	REVISION DETAILS	APPROVED	SCALE	SIZE
water & sanitation Department: Water and Sanitation REPUBLIC OF SOUTH AFRICA	IF CONSTRUCTION DRAWINGS ARE ISSUED UNSIGNED, THE MASTER WITH THE ORIGINAL SIGNATURE OF APPROVAL WILL BE HELD AT THE ZUTARI OFFICE OF THE APPROVER	A	07.09.20	FOR INFORMATION	G.DAVIS	1:5000	A1

DRAWN: D.BULL
DESIGNED: G.DAVIS
REVIEWED: G.DAVIS

INFORMATION
NOT FOR CONSTRUCTION

APPROVED
DATE

PROJECT: CLANWILLIAM BRIDGING STUDY

TITLE: JAN DISSELS TEST PIT LAYOUT PLAN SHEET 01 OF 01

DRAWING No.	PROJECT No.	WBS	TYPE	DISC	NUMBER	REV
	113834	0000	DRG	GG	0001	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

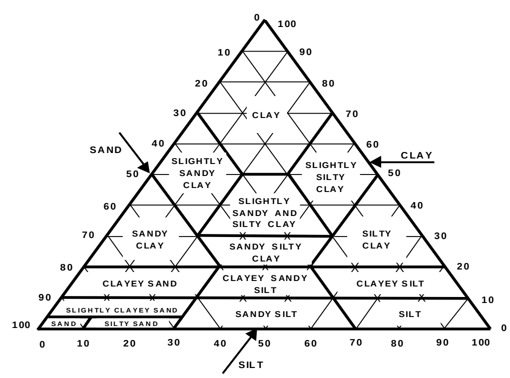
Term	Description
Intact	Absence of fissures or joints
Fissured	Presence of closed joints
Shattered	Presence of closely spaced air-filled joints giving cubical fragments
Micro-shattered	Small scale shattering with shattered fragments the size of sand grains
Slickensided	Polished planar surfaces representing 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 and Photographs

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

JOB NUMBER: **113834**

Scale
1:30

0.00
0.10

Could not be accessed with the TLB but its on sandstone boulders and possible shallow bedrock.
Talus
DCP was conducted at this location.

NOTES:

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	TLB	DIAM:		X COORD:	- 9846
PROFILED BY:	S Nyathi and M Sikwe	DATE DRILLED:	7/15/2020	Y COORD:	- 3565029
TYPE SET BY:		DATE PROFILED:	7/15/2020		
	JAN DIESEL SCHEME.GPJ				

HOLE No: JD-TP01

aurecon

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Jan Dissels Scheme

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

JOB NUMBER: **113834**

Scale 1:30

0.00
0.10

Could not be accessed with the TLB but its on sandstone boulders and possible shallow bedrock.
Talus
DCP was conducted at this location.

NOTES:

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
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PROFILED BY:	S Nyathi and M Sikwe	DATE DRILLED:	7/15/2020	Y COORD:	- 3565059
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	JAN DIESEL SCHEME.GPJ				

HOLE No: **JD-TP02**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Jan Dissels Scheme

HOLE No: **JD-TP03**
Sheet 1 of 1

JOB NUMBER: **113834**

Scale 1:30

0.00 – 0.10	Could not be accessed with the TLB but its on sandstone boulders and possible shallow bedrock. Talus

NOTES:

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
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	JAN DIESEL SCHEME.GPJ				

HOLE No: **JD-TP03**

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Bridging Study Clanwilliam Dam
Jan Dissels Scheme

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

JOB NUMBER: **113834**

Scale 1:30
sample ●

0.00 – 0.40	Moist, brown , VERY LOOSE, intact, SAND with roots. Colluvium
0.40 – 1.00	Moist, brown, VERY LOOSE, intact, SAND with sandstone gravel and boulders (<1.5m diameter). Residual quartzitic sandstone

NOTES:

1. Refusal on hard rock sandstone boulders.
2. No groundwater or seepage encountered.
3. Sidewalls collapsed.
4. Small and bulk sampling between 0.0-0.4m.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
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PROFILED BY:	S Nyathi and M Sikwe	*DATE DRILLED:*	7/15/2020	*Y COORD:*	- 3564843
TYPE SET BY:		*DATE PROFILED:*	7/15/2020		
	JAN DIESEL SCHEME.GPJ				

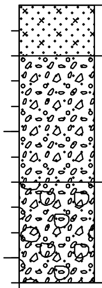
HOLE No: **JD-TP04**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Jan Dissels Scheme

HOLE No: **JD-TP05**

JOB NUMBER: **113834**

Scale 1:30



0.00 – 0.20	Moist to very moist, brown, LOOSE, intact, silty SAND. Topsoil
0.20 – 0.70 (sample)	Moist to very moist, brown to grey brown, MEDIUM DENSE TO DENSE, matrix-supported, gravelly SAND. Colluvium
0.70 – 1.10	Pink to red,highly to completely weathered and friable, clast-supported soft rock quartzitic sandstone gravel and cobbles in a matrix of moist brown sand. Overall consistency is medium dense to very dense. Residual quartzitic sandstone

NOTES:

1. Refusal on hard rock quartzitic sandstone bedrock, rock outcrop in the area.
2. No groundwater or seepage encountered.
3. Sidewalls were stable.
4. Small and bulk sampling between 0.2-0.7m.

CONTRACTOR: DWS
MACHINE: TLB
PROFILED BY: G Davis and K Mybrugh
TYPE SET BY:
JAN DIESEL SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/15/2020
DATE PROFILED: 7/15/2020

ELEVATION:
X COORD: - 9597
Y COORD: - 3564767

HOLE No: **JD-TP05**

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Bridging Study Clanwilliam Dam
Jan Dissels Scheme

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

JOB NUMBER: **113834**

Scale 1:30

0.00–0.15	Moist to very moist, brown, VERY LOOSE, intact, silty SAND. Colluvium
0.15–1.00	Moist, reddish brown, LOOSE TO MEDIUM DENSE, matrix-supported, gravelly SAND. Residual quartzitic sandstone

sample

NOTES:

1. Refusal on hard rock quartzitic sandstone bedrock, rock outcrop in the area.
2. No groundwater or seepage encountered.
3. Sidewalls were stable.
4. Small bag sampled between 0.15-1.0m.

CONTRACTOR: DWS
MACHINE: TLB
PROFILED BY: G Davis and K Mybrugh
TYPE SET BY:
JAN DIESEL SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/15/2020
DATE PROFILED: 7/15/2020

ELEVATION:
X COORD: - 9540
Y COORD: - 3564763

HOLE No: **JD-TP06**

Report ID: _ZA TRAIL PIT LOG || Project: JAN DIESEL SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: September 10, 2020

Scale
1:30

0.00
0.30

Clast-supported, sub-angular to angular, red, very hard rock, quartzitic sandstone GRAVEL, cobbles and boulders, in a matrix of moist, brown silty sand. Overall consistency is very loose. Residual quartzitic sandstone.

NOTES:

1. Refusal on medium hard rock quartzitic sandstone bedrock, rock outcrop in the area.
2. No groundwater or seepage encountered.
3. Sidewalls were stable.
4. No sample was taken.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	TLB	DIAM:		X COORD:	- 9587
PROFILED BY:	G Davis and K Mybrugh	DATE DRILLED:	7/15/2020	Y COORD:	- 3564705
TYPE SET BY:		DATE PROFILED:	7/15/2020		
	JAN DIESEL SCHEME.GPJ				

HOLE No: **JD-TP07**

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Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Jan Dissels Scheme

JOB NUMBER: **113834**

Scale
1:30

0.00 – 0.30	Very Moist, brown , LOOSE, intact, SAND with red, sub-angular, sandstone gravel and cobbles. Colluvium

NOTES:

1. Refusal on very soft rock quartzitic sandstone.
2. No groundwater or seepage encountered.
3. Sidewalls were stable.
4. No sample was taken.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	TLB	DIAM:		X COORD:	- 9751
PROFILED BY:	S Nyathi and M Sikwe	DATE DRILLED:	7/14/2020	Y COORD:	- 3564426
TYPE SET BY:		DATE PROFILED:	7/14/2020		

JAN DIESEL SCHEME.GPJ

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Bridging Study Clanwilliam Dam
Jan Dissels Scheme

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

JOB NUMBER: **113834**

Scale 1:30

sample

0.00	Slightly moist, light yellow brown, VERY LOOSE TO LOOSE, silty SAND with roots on the upper 200mm. Colluvium
1.10	Dry, light yellow brown, MEDIUM DENSE, fine SAND with angular, medium gravel. Colluvium
1.80	

NOTES:

1. Refusal on tighly packed gravel.
2. No groundwater or seepage encountered.
3. Sidewalls were stable.
4. Bulk sample between 0.0-1.1m.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	TLB	DIAM:		X COORD:	- 9874
PROFILED BY:	G Davis and K Mybrugh	DATE DRILLED:	7/14/2020	Y COORD:	- 3564149
TYPE SET BY:		DATE PROFILED:	7/14/2020		

JAN DIESEL SCHEME.GPJ

HOLE No: **JD-TP09**

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Bridging Study Clanwilliam Dam
Jan Dissels Scheme

HOLE No: **JD-TP10**

Sheet 1 of 1

JOB NUMBER: **113834**

Scale 1:30

0.00 – 0.70	Very Moist, dark brown mottled red and orange, MEDIUM DENSE TO DENSE, intact, ferruginised clayey silty SAND. Residual quartzitic sandstone

sample

NOTES:

1. Refusal on very soft rock quartzitic sandstone.
2. No groundwater or seepage encountered.
3. Sidewalls were stable.
4. Small and bulk sampling between 0.0-0.7m.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	TLB	*DIAM:*		*X COORD:*	- 9975
PROFILED BY:	S Nyathi and M Sikwe	*DATE DRILLED:*	7/14/2020	*Y COORD:*	- 3563855
TYPE SET BY:		*DATE PROFILED:*	7/14/2020		

JAN DIESEL SCHEME.GPJ

HOLE No: **JD-TP10**

HOLE No: **JD-TP11**

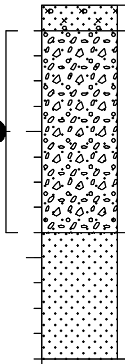
Sheet 1 of 1

JOB NUMBER: **113834**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Jan Dissels Scheme

Scale 1:30

sample



0.00 – 0.10	Slightly moist to moist, grey brown, LOOSE, silty SAND, with gravels, Colluvium
0.10 – 0.90	Orange red, clast supported, highly weathered soft rock to medium hard, sub-angular, rock cobbles and boulders of quartzitic sandstone with occasional matrix of silty SAND. Residual quartzitic sandstone
0.90 – 1.40	Orange red, moderate to highly weathered, excavated as angular boulders and cobbles, medium hard rock. Quartzitic sandstone

NOTES:

1. Refusal on medium hard quartzitic sandstone bedrock.
2. No groundwater or seepage encountered.
3. Sidewalls were stable, but note loose boulders.
4. Small bag sampling between 0.1-0.9m.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	TLB	DIAM:		X COORD:	- 10125
PROFILED BY:	G Davis and K Mybrugh	DATE DRILLED:	7/14/2020	Y COORD:	- 3563580
TYPE SET BY:		DATE PROFILED:	7/14/2020		
	JAN DIESEL SCHEME.GPJ				

HOLE No: **JD-TP11**

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

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

JOB NUMBER: **113834**

Scale 1:30

0.00 – 0.50	sample	Very moist, brown, LOOSE, intact, SAND. Colluvium
0.50 – 2.30		Clast-supported, angular, red-brownish, very hard rock, sandstone GRAVEL, cobbles and boulders, and localised very soft rock siltstone at 1.8 to 2.3 m, in a matrix of moist to very moist, brown sand. Overall consistency is loose. Residual quartzitic sandstone

NOTES:

1. Refusal on soft rock quartzitic sandstone.
2. No groundwater or seepage encountered.
3. Sidewalls collapsed.
4. Small bag sample between 0.0-0.5m.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	TLB	*DIAM:*		*X COORD:*	- 10341
PROFILED BY:	G Davis and K Mybrugh	*DATE DRILLED:*	7/14/2020	*Y COORD:*	- 3563410
TYPE SET BY:		*DATE PROFILED:*	7/14/2020		
	JAN DIESEL SCHEME.GPJ				

HOLE No: **JD-TP12**

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Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Jan Dissels Scheme

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

JOB NUMBER: **113834**

Scale 1:30

0.00	Moist, brown to red brown, LOOSE TO MEDIUM DENSE, intact, clayey SAND. Residual quartzitic sandstone
1.10 – 1.30	Completely to highly weathered, soft to medium hard and hard rock sandstone with dry to slightly moist, very dense sand in places. Quartzitic sandstone

NOTES:

1. Refusal on hard quartzitic sandstone bedrock.
2. No groundwater or seepage encountered.
3. Sidewalls were stable.
4. No sample was taken.

CONTRACTOR: DWS
MACHINE: TLB
PROFILED BY: G Davis and K Mybrugh
TYPE SET BY:
JAN DIESEL SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/14/2020
DATE PROFILED: 7/14/2020

ELEVATION:
X COORD: - 10511
Y COORD: - 3563120

HOLE No: **JD-TP13**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Jan Dissels Scheme

JOB NUMBER: **113834**

Scale 1:30

0.00	Slightly moist, light yellow brown, LOOSE, intact, SAND with roots. Colluvium
1.60	Slightly moist to moist, yellow to red brown, DENSE, intact, slightly clayey SAND. Residual quartzitic sandstone
2.10	

sample

NOTES:

1. Refusal on medium hard quartzitic sandstone bedrock.
2. No groundwater or seepage encountered.
3. Sidewalls were stable, but minor slip during excavation.
4. Small bag sampling between 0.0-1.6m.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	TLB	DIAM:		X COORD:	- 10666
PROFILED BY:	S Nyathi and M Sikwe	DATE DRILLED:	7/14/2020	Y COORD:	- 3562908
TYPE SET BY:		DATE PROFILED:	7/14/2020		

JAN DIESEL SCHEME.GPJ

Report ID: _ZA TRAIL PIT LOG || Project: JAN DIESEL SCHEME.GPJ || Library: GINT STD AGS 4_0_SA.GLB || Date: September 10, 2020

aurecon

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Jan Dissels Scheme

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

JOB NUMBER: **113834**

Scale 1:30

0.00	Very moist, brown, LOOSE, intact, SAND. Colluvium
0.70	Very moist, brownish red, DENSE, stratified, gravelly SAND. Residual quartzitic sandstone
1.20	

sample

NOTES:

1. Refusal on very soft rock quartzitic sandstone bedrock.
2. No groundwater seepage was encountered.
3. Sidewalls collapsed.
4. Bulk smapled between 0.7-1.2 from the fines.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	TLB	DIAM:		X COORD:	- 10870
PROFILED BY:	G Davis and K Mybrugh	DATE DRILLED:	7/14/2020	Y COORD:	- 3562691
TYPE SET BY:		DATE PROFILED:	7/14/2020		

JAN DIESEL SCHEME.GPJ

HOLE No: **JD-TP15**

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

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Jan Dissels Scheme

JOB NUMBER: **113834**

Scale 1:30

0.00	Clast-supported, angular to sub-angular, red-brownish, very hard rock, sandstone GRAVEL, cobbles and boulders, in a matrix of moist to very moist, brown sand. Overall consistency is very loose. Residual quartzitic sandstone
1.40	Clast-supported, angular to sub-angular, red-brownish, very hard rock, sandstone GRAVEL, cobbles and boulders, in a matrix of moist to very moist, red brown sand. Overall consistency is loose. Residual quartzitic sandstone
1.70	

sample

NOTES:

1. Refusal on the boulders.
2. No groundwater seepage was encountered.
3. Sidewalls collapsed.
4. Small bag smapled between 0.0-1.4 from the fines.

CONTRACTOR: DWS
MACHINE: TLB
PROFILED BY: S Nyathi and M Sikwe
TYPE SET BY:
JAN DIESEL SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/14/2020
DATE PROFILED: 7/14/2020

ELEVATION:
X COORD: - 11098
Y COORD: - 3562573

HOLE No: **JD-TP16**

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Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Jan Dissels Scheme

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

JOB NUMBER: **113834**

Scale 1:30

0.00 – 0.40	Clast-supported, sub-angular to sub-rounded, red-brownish, very hard rock, sandstone GRAVEL cobbles and boulders, in a matrix of very moist, brown silty sand. Overall consistency is very loose. Colluvium
0.40 – 5.00	Off-white stained pink, moderately to slightly weathered, thickly and sub-horizontaly bedded, very closely to moderately jointed, infill silty sand (<20cm) and open very hard rock. Quartzitic sandstone

NOTES:

1. Cut face not test pit.
2. No groundwater seepage was encountered.
3. Sidewalls stable, excavated not blasted
4. No sample was taken.

CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	TLB	*DIAM:*		*X COORD:*	- 11534
PROFILED BY:	G Davis and K Mybrugh	*DATE DRILLED:*	7/14/2020	*Y COORD:*	- 3562521
TYPE SET BY:		*DATE PROFILED:*	7/14/2020		

JAN DIESEL SCHEME.GPJ

HOLE No: **JD-TP17**

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Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Jan Dissels Scheme

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

JOB NUMBER: **113834**

Scale 1:30

0.00	Very Moist, brown , LOOSE, clayey SAND with fine gravel, in places up to 1m thick with cobbles that are fractured. Colluvium
0.35	Moderately weathered, thickly bedded, very hard rock (excavation to require blasting, its close to the dam). Quartzitic sandstone
3.00	

NOTES:

1. Cut face not test pit.
2. No groundwater seepage was encountered.
3. Sidewalls stable, excavated not blasted
4. No sample was taken.

CONTRACTOR: DWS
MACHINE: TLB
PROFILED BY: S Nyathi and M Sikwe
TYPE SET BY:
JAN DIESEL SCHEME.GPJ

INCLINATION:
DIAM:
DATE DRILLED: 7/14/2020
DATE PROFILED: 7/14/2020

ELEVATION:
X COORD: - 11637
Y COORD: - 3562316

HOLE No: **JD-TP18**

Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Jan Dissels Scheme

JOB NUMBER: **113834**

Scale 1:30

0.00

ACTUAL RIGHT PLANK OF THE DAM, slope is characterized by the large blocks up to 2m quartzitic sandstone. randomly distributed with old terrances from the construction of the dam, very hard rock, deep cuts of slope at the shallow angles. Quartzitic sandstone

2.00

NOTES:

1. Cut face not test pit.
2. No groundwater seepage was encountered.
3. Sidewalls stable, excavated not blasted
4. No sample was taken.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	TLB	DIAM:		X COORD:	- 11739
PROFILED BY:	G Davis and K Mybrugh	DATE DRILLED:	7/14/2020	Y COORD:	- 3562252
TYPE SET BY:		DATE PROFILED:	7/14/2020		
	JAN DIESEL SCHEME.GPJ				

HOLE No: **JD-TP19**

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

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

JOB NUMBER: **113834**

Scale
1:30

0.00 – 0.20	Very Moist, dark brown and grey , MEDIUM DENSE, intact, silty SAND and wet roots. Colluvium
0.20 – 0.50	off white and orange, moderately to slightly weathered, coarse grained, bedded, hard rock. Quartiztic sandstone

NOTES:

1. Refusal on hard rock sandstone.
2. No groundwater or seepage encountered.
3. Sidewalls were stable.
4. No sample was taken.

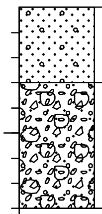
CONTRACTOR:	DWS	*INCLINATION:*		*ELEVATION:*	
MACHINE:	TLB	*DIAM:*		*X COORD:*	- 9707
PROFILED BY:	S Nyathi and M Sikwe	*DATE DRILLED:*	7/15/2020	*Y COORD:*	- 3564746
TYPE SET BY:		*DATE PROFILED:*	7/15/2020		
	JAN DIESEL SCHEME.GPJ				

HOLE No: **JD-TP20**

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

JOB NUMBER: **113834**

Scale 1:20
sample



0.00 – 0.30	Moist, dark brown , LOOSE, intact, slightly gravely SAND. Colluvium
0.30 – 0.80	Clast-supported, sub-angular to sub-rounded, red-brownish, hard rock, quartzitic sandstone GRAVEL cobbles and boulders (<600mm), in a matrix of very moist, brown silty sand. Overall consistency is loose. Residual quartzitc sandstone

NOTES:

1. Refusal on hard rock sandstone boulders.
2. No groundwater or seepage encountered.
3. Sidewalls collapsed.
4. Small bag sampled between 0.0-0.3m.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	TLB	DIAM:		X COORD:	- 9788
PROFILED BY:	G Davis and K Mybrugh	DATE DRILLED:	7/15/2020	Y COORD:	- 3564905
TYPE SET BY:		DATE PROFILED:	7/15/2020		

JAN DIESEL SCHEME.GPJ

HOLE No: **JD-TP21**

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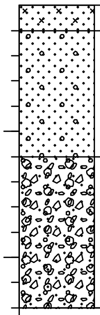
Department of Water and Sanitation
Bridging Study Clanwilliam Dam
Jan Dissels Scheme

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

JOB NUMBER: **113834**

Scale 1:30



sample

0.00 – 0.10	Moist to very moist, brown , LOOSE, intact, silty SAND. Topsoil
0.10 – 0.60	Moist to very moist, brown, LOOSE TO MEDIUM DENSE, matrix-supported, gravelly SAND. Colluvium
0.60 – 1.20	Pink to red,highly to completely weathered and friable, clast-supported soft rock quartzitic sandstone GRAVEL and cobbles in a matrix of moist brown sand. Overall consistency is medium dense to very dense. Residual quartzitic sandstone

NOTES:

1. Refusal on hard rock quartzitic sandstone bedrock, rock outcrop in the area.
2. No groundwater or seepage encountered.
3. Sidewalls were stable.
4. Small and bulk sampling between 0.6-1.2m.

CONTRACTOR:	DWS	INCLINATION:		ELEVATION:	
MACHINE:	TLB	DIAM:		X COORD:	- 11459
PROFILED BY:	G Davis and K Mybrugh	DATE DRILLED:	7/15/2020	Y COORD:	- 3562218
TYPE SET BY:		DATE PROFILED:	7/15/2020		

JAN DIESEL SCHEME.GPJ

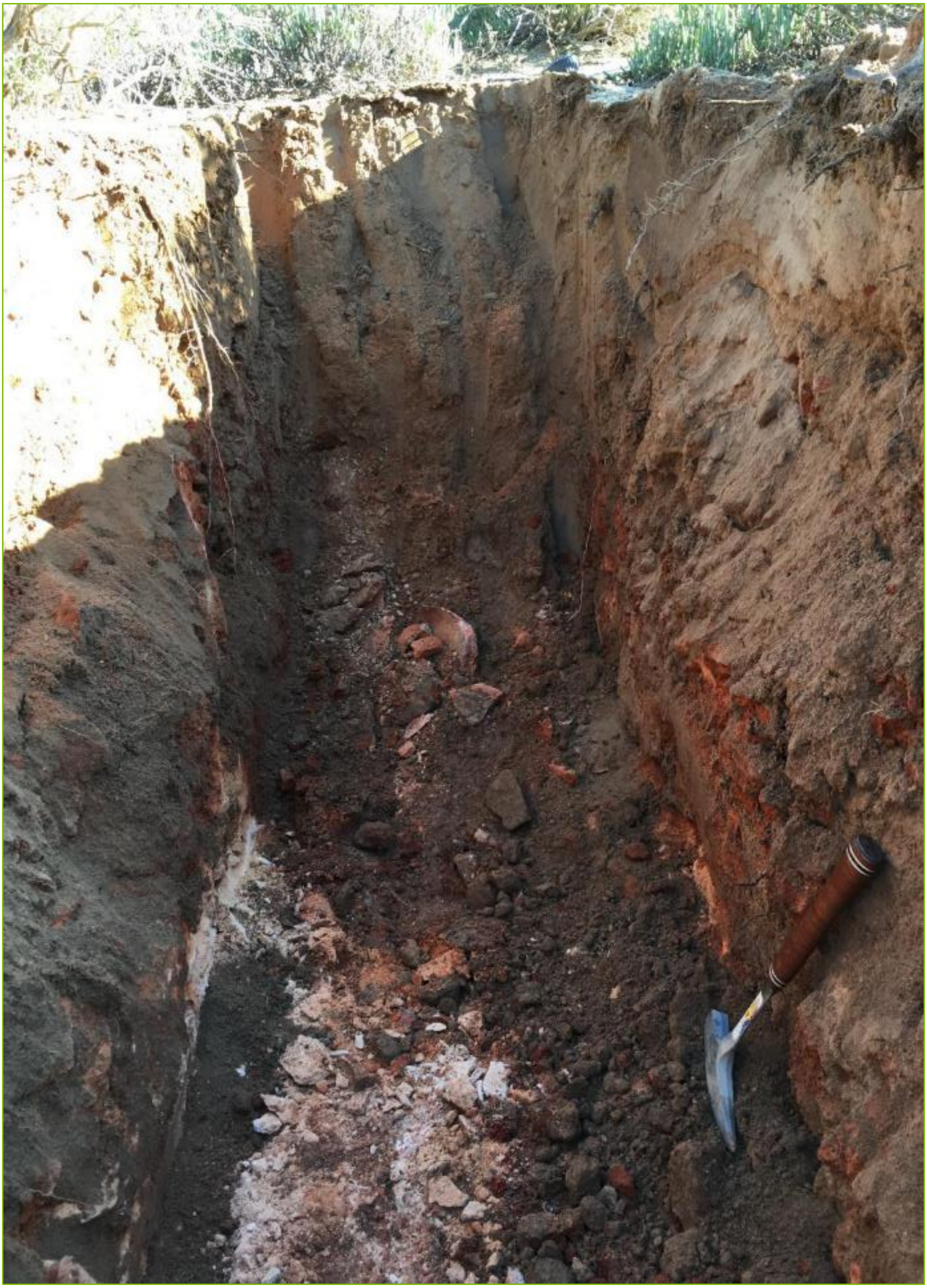
HOLE No: **JD-TP22**

JD-TP01

JD-TP02

TP 3

JD-TP04

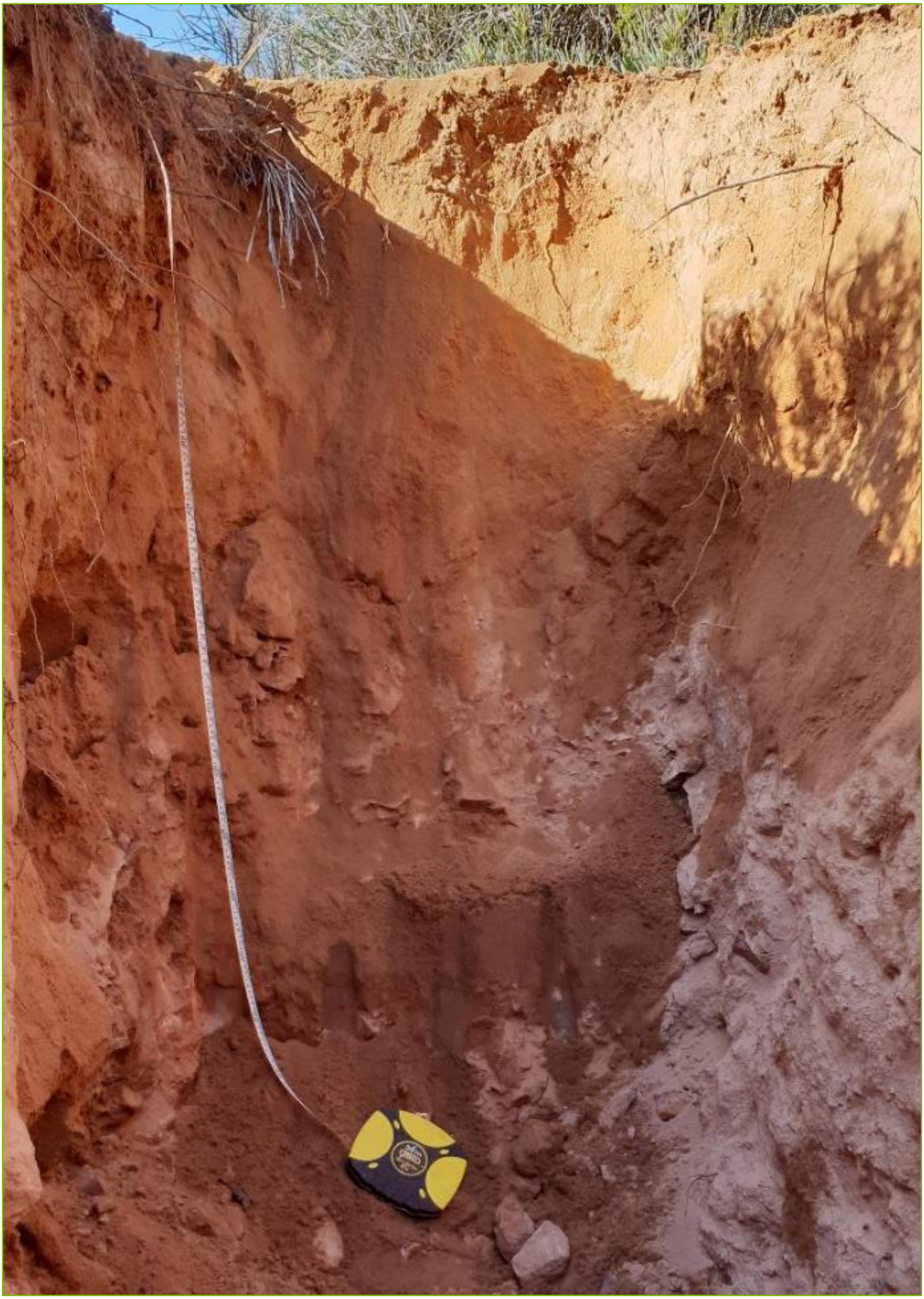


JD-TP05

JD-TP06

JD-TP07

JD-TP08



JD-TP09

JD-TP10

JD-TP11

JD-TP12

JD-TP13

JD-TP14

JD-TP15

JD-TP16

JD-TP17

JD-TP18

JD-TP19

JD-TP20

JD-TP21

JD-TP22

Appendix D
DCP Test Results

ZUTARI

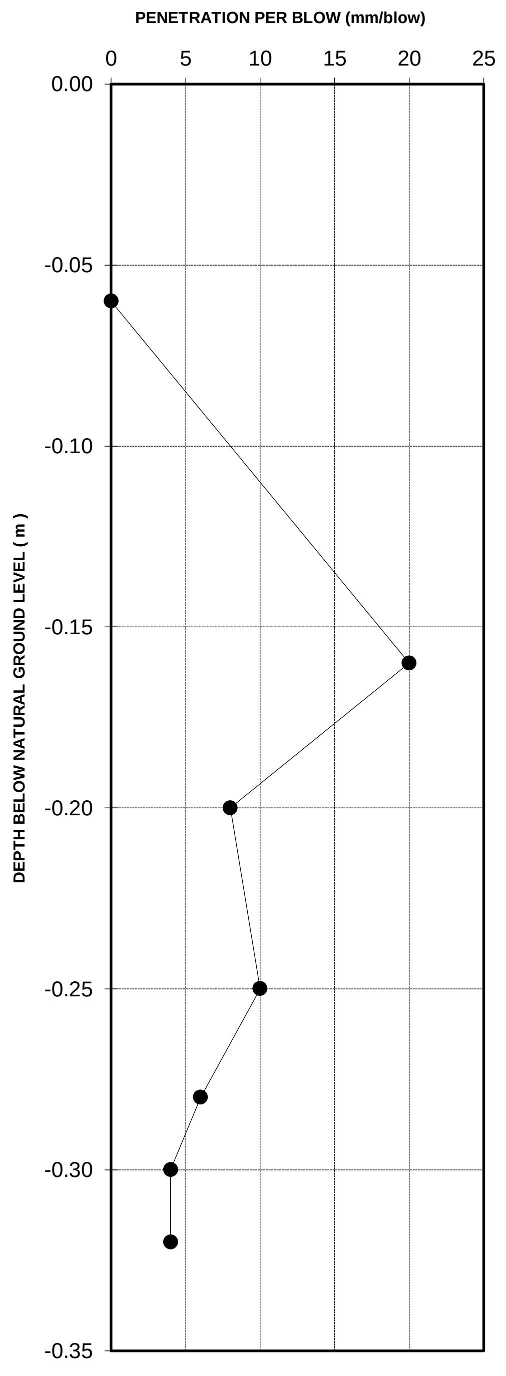
Ground and Pavement Engineering

DYNAMIC CONE PENETRATION TEST

PROJECT	Bridging Study Clanwilliam Dam
PROJECT NUMBER	113834
TEST LOCATION	JD-TP01
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	60	-0.060	#DIV/0!	#DIV/0!	0
5	160	-0.160	20	5	108
10	200	-0.200	8	13	270
15	250	-0.250	10	10	216
20	280	-0.280	6	17	360
25	300	-0.300	4	25	540
30	320	-0.320	4	25	540

GRAPH



** From " RULE OF THUMB METHOD" by I S VENTER

ZUTARI

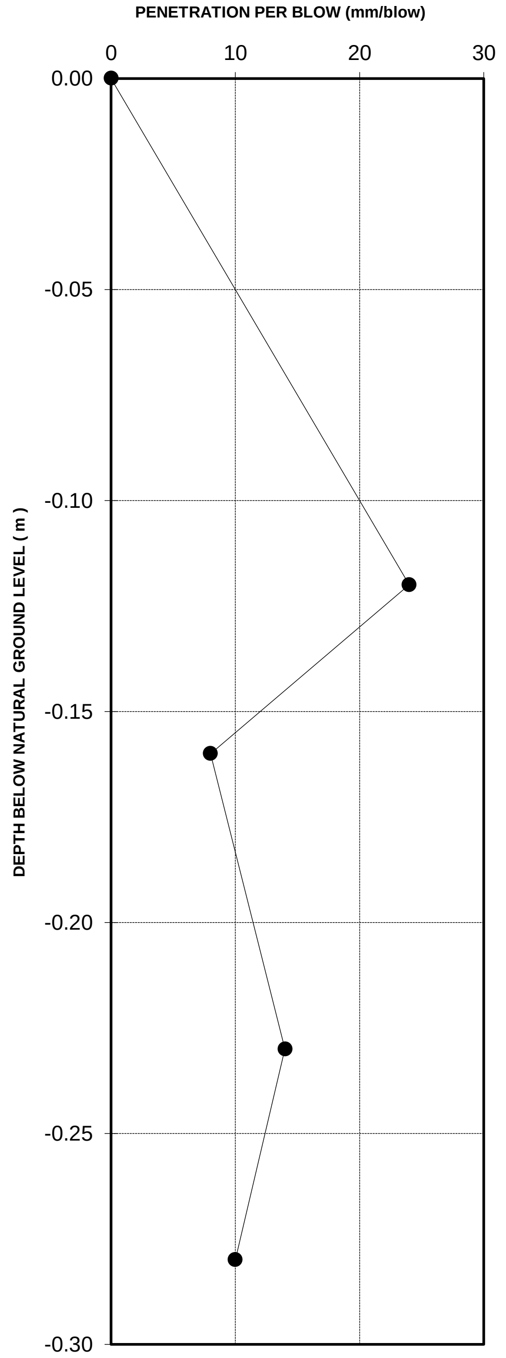
Ground and Pavement Engineering

DYNAMIC CONE PENETRATION TEST

PROJECT	Bridging Study Clanwilliam Dam
PROJECT NUMBER	113834
TEST LOCATION	JD-TP02
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	0	0.000	0	0	0
5	120	-0.120	24	4	90
10	160	-0.160	8	13	270
15	230	-0.230	14	7	154
20	280	-0.280	10	10	216

GRAPH



** From " RULE OF THUMB METHOD" by I S VENTER

Appendix E
Laboratory Test Results

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:	Jan Dissels
Attention:	Ms K Myburgh
Your Ref. No:	113834
Date Reported	31.07.20

TEST REPORT REFERENCE NUMBER / JOB NUMBER : SWL12317

Dear Sir / Madam

Herewith please find the original reports pertaining to the above mentioned project.

Test Requested

4	*x FOUNDATION INDICATOR*
3	*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.

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

Customer : **Zutari**
1 Century City Drive
Century City
7446
Attention : Ms K Myburgh

Project : Jan Dissels
Date Received : 20.07.20
Date Reported : 31.07.20
Req. Number : 113834

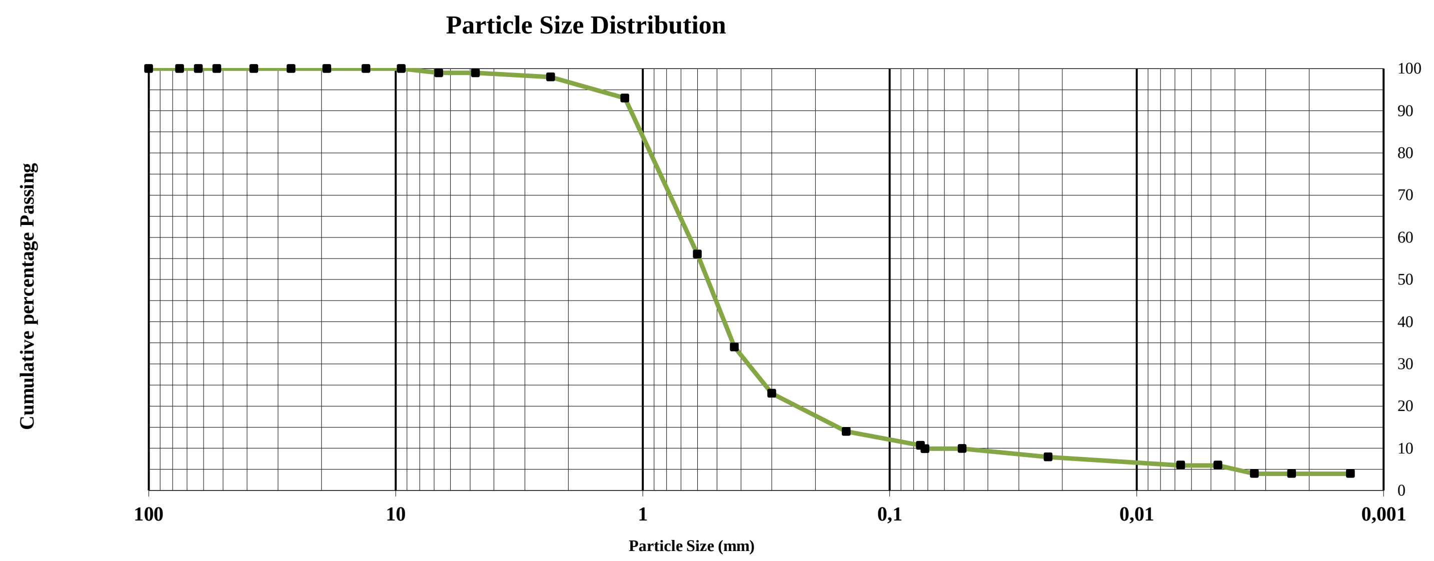
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Light Brown Coarse Sand	Sample Number:	13592		
Position:	JD TP04	Liquid Limit	NP	Linear Shrinkage	0.0
Depth:	0.0 - 0.4m	Plasticity Index	NP	Insitu M/C%	3,2

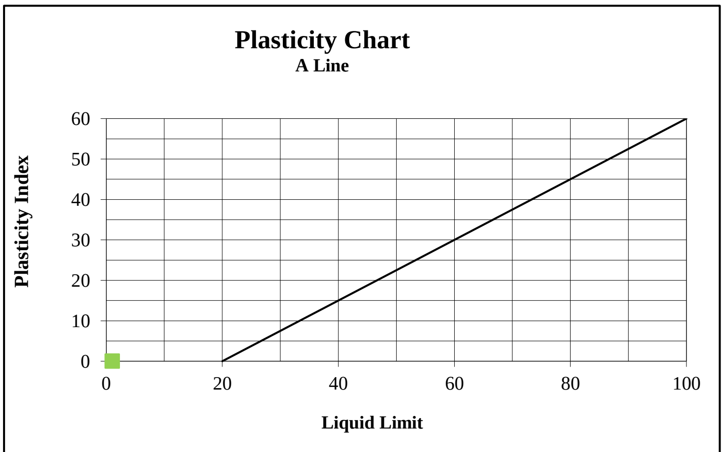
pH (TMH1 A20)*	4,2	Conductivity s.m-1 (TMH1 A21T)*	0,008	COLTO SPEC	G9

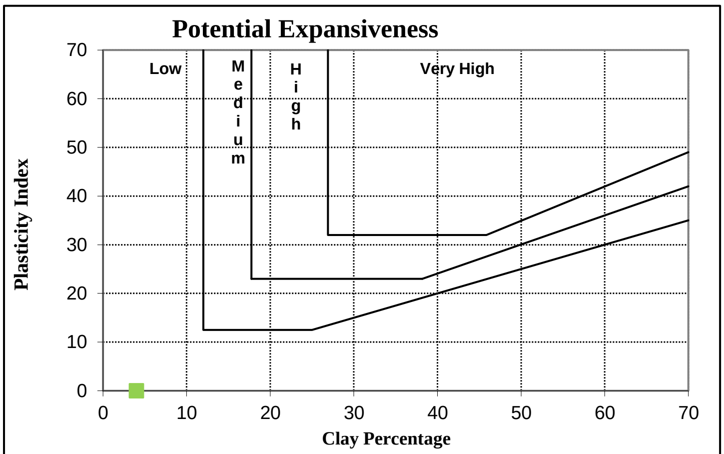
SIEVE ANALYSIS (TMH 1 A1a)*																		HYDROMETER ASTM D422							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,072	0,051	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	99	99	98	93	56	34	23	14	10,7	9,9	9,9	7,92	5,94	5,94	3,96	3,96	3,96
% Passing																									

MOD AASHTO SANS 3001 GR30		CBR SANS 3001 GR40							
OMC%	11,2	COMP MC	% SWELL	100%	98%	97%	95%	93%	90%
MDD(KG/M³)	1926	10,8	0,0	18	14	13	10	8	5



% Gravel	4	% Sand	86	% Silt	6	% Clay	4





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

Customer :	**Zutari**	Project :	Jan Dissels
	1 Century City Drive	Date Received :	20.07.20
	Century City	Date Reported :	31.07.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

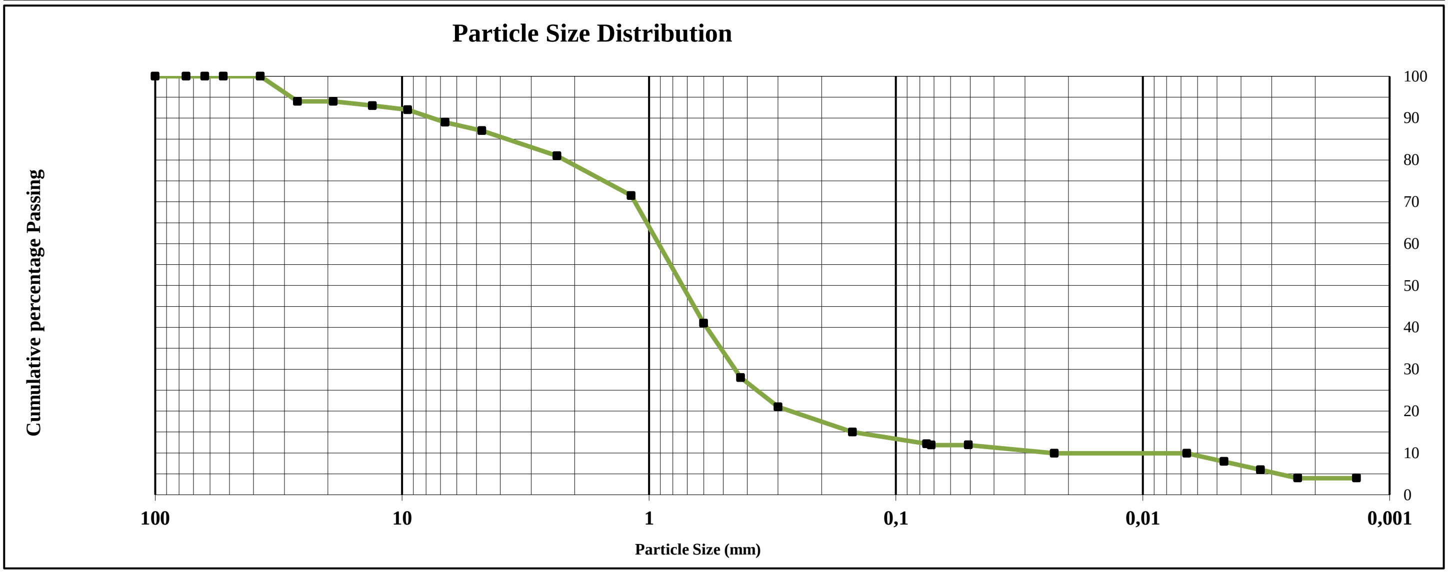
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Dark Brown Coarse Soil with Quartzitic Sandstone	Sample Number:	13593		
Position:	JD TP05	Liquid Limit	**NP**	Linear Shrinkage	**0,0**
Depth:	0.2 - 0.7m	Plasticity Index	**NP**	Insitu M/C%	**4**

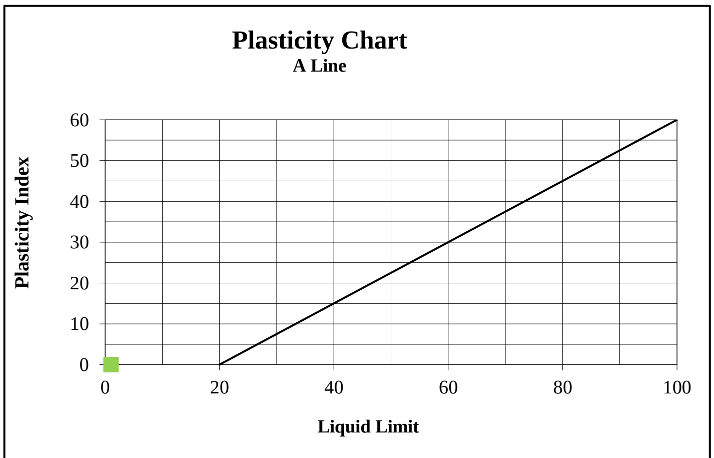
PH (TMH1 A20)*	**4,5**	**(TMH1 A21T)* Conductivity s.m^{-1}**	**0,011**	**COLTO SPEC**	**G6**

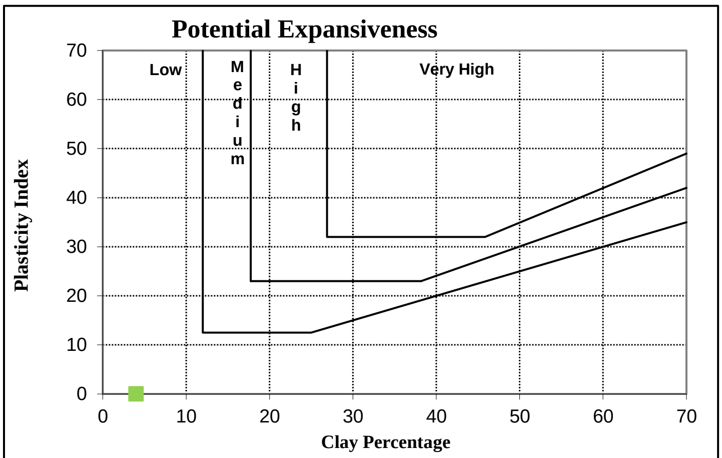
SIEVE ANALYSIS (TMH 1 A1a)*																		HYDROMETER ASTM D422							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,072	0,051	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	94	94	93	92	89	87	81	71,5	41	28	21	15	12,2	11,88	11,88	9,9	9,9	7,92	5,94	3,96	3,96
% Passing																									

MOD AASHTO SANS 3001 GR30		CBR SANS 3001 GR40							
OMC%	8,3	**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)	2170	8	0,0	80	59	46	32	22	13



% Gravel	**22**	**% Sand**	**66**	**% Silt**	**8**	**% Clay**	**4**





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

Customer :	**Zutari**	Project :	Jan Dissels
	1 Century City Drive	Date Received :	20.07.20
	Century City	Date Reported :	31.07.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

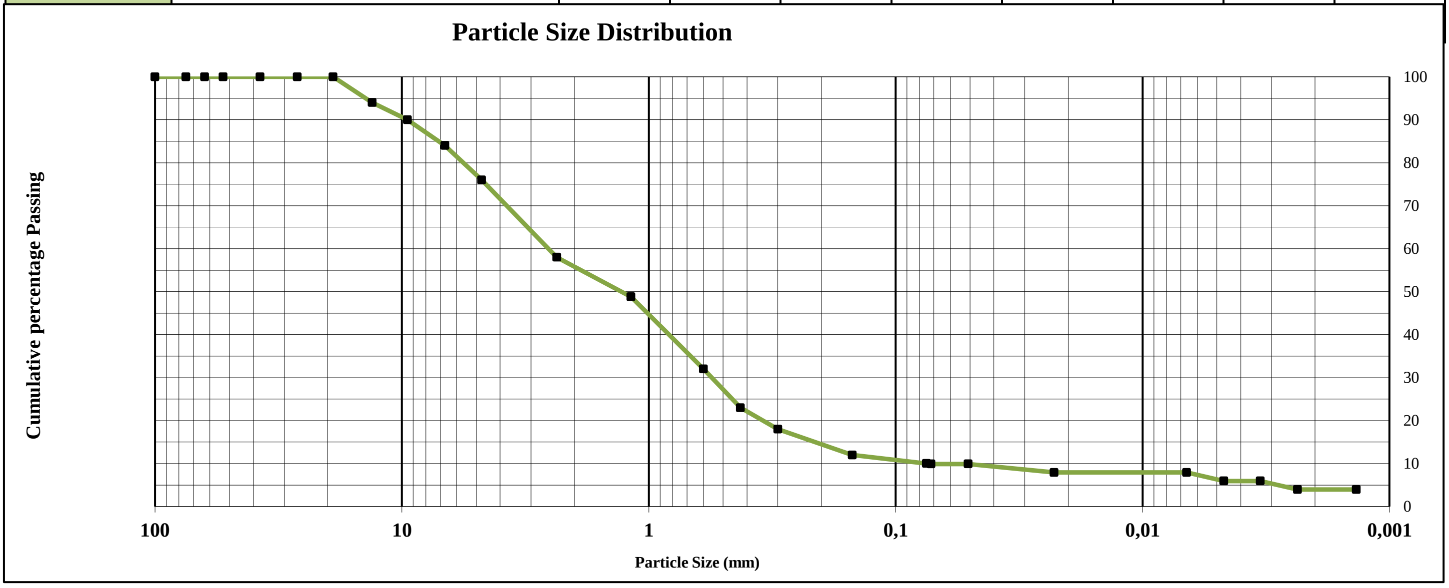
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Dark Brown Reddish Sand with Quartzitic Sandstone	Sample Number:	13594		
Position:	JD TP06	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.15- 1.0m	Plasticity Index	**NP**	Insitu M/C%	**4**

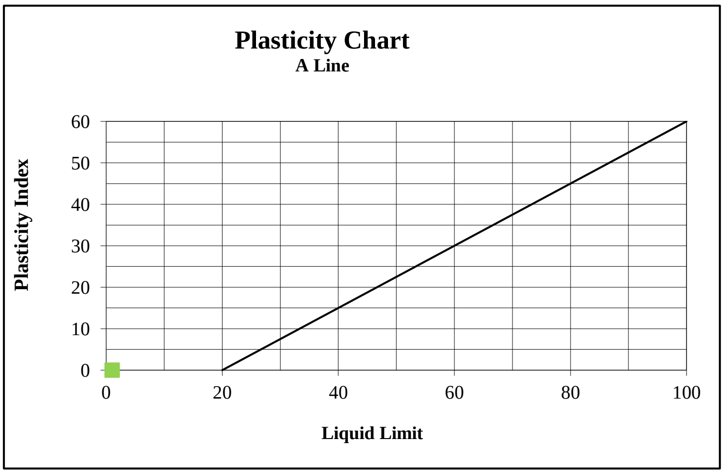
PH (TMH1 A20)*	-	**(TMH1 A21T)* Conductivity s.m^{-1}**	-	**COLTO SPEC**	

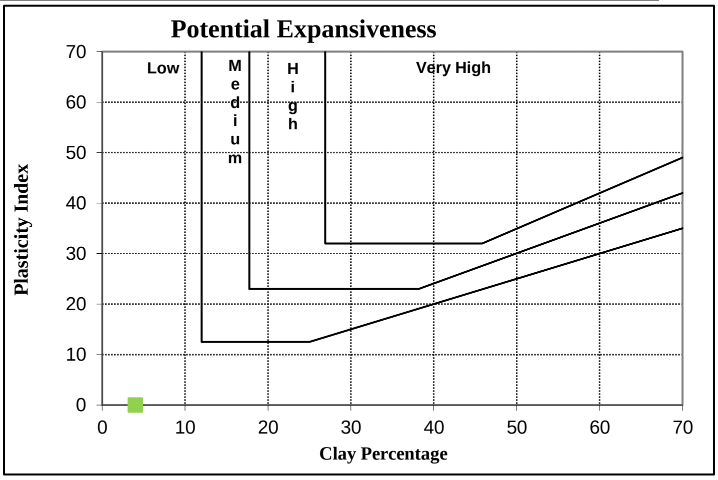
SIEVE ANALYSIS (TMH 1 A1a)*																		**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,072	0,051	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	94	90	84	76	58	48,8	32	23	18	12	10	9,9	9,9	7,92	7,92	5,94	5,94	3,96	3,96
% 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	45	**% Sand**	45	**% Silt**	6	**% Clay**	4





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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

Customer :	**Zutari**	Project :	Jan Dissels
	1 Century City Drive	Date Received :	20.07.20
	Century City	Date Reported :	31.07.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

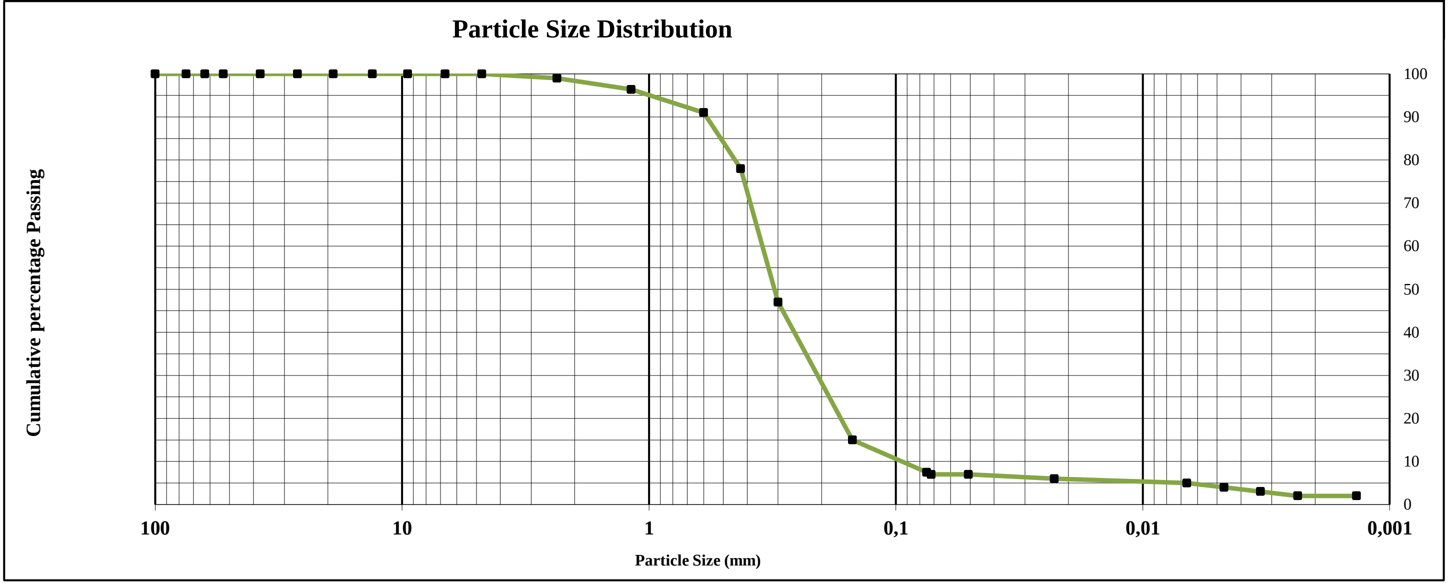
Material Description:	Light Brown Sand with Sandstone	Sample Number:	13595		
Position:	JD TP09	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.0 - 1.1m	Plasticity Index	**NP**	Insitu M/C%	**4,1**

PH (TMH1 A20)*	**5,1**	**(TMH1 A21T)* Conductivity s.m^{-1}**	**0,022**	**COLTO SPEC**	**G9**

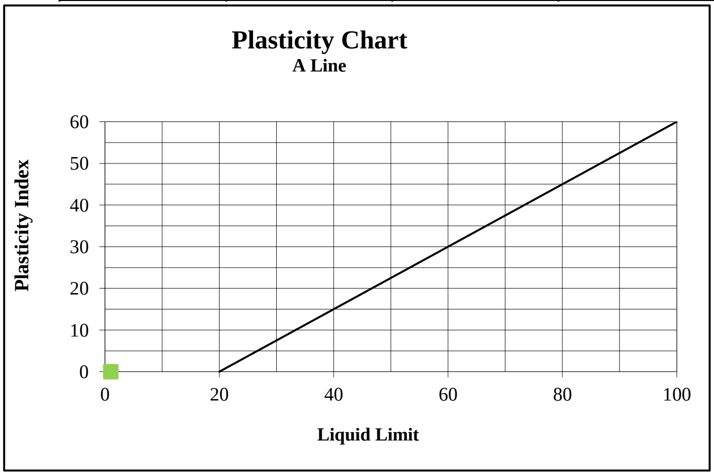
SIEVE ANALYSIS (TMH 1 A1a)*																	HYDROMETER ASTM D422							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,072	0,051	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	100	99	96,4	91	78	47	15	7,5	7	7	6	5	4	3	2	2

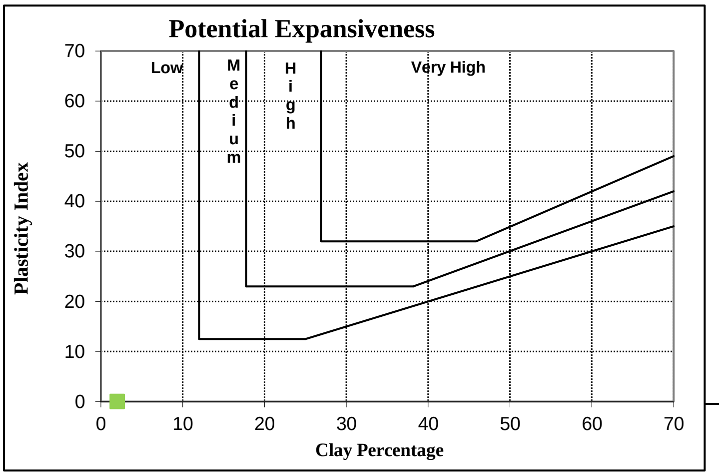
% Passing

MOD AASHTO SANS 3001 GR30		CBR SANS 3001 GR40							
OMC%	13,1	**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)	1843	13	0,0	14	12	11	9	8	6



% Gravel	2	% Sand	91	% Silt	5	% Clay	2





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Client: **Zutari**
Project: Jan Dissels
Attention: Ms K Myburgh
Your Ref. No: 113834
Date Reported 31.07.20

TEST REPORT REFERENCE NUMBER / JOB NUMBER : SWL12317

Dear Sir / Madam

Herewith please find the original reports pertaining to the above mentioned project.

Test Requested

4 x FOUNDATION INDICATOR
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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Customer :	**Zutari**	Project :	Jan Dissels
	1 Century City Drive	Date Received :	20.07.20
	Century City	Date Reported :	31.07.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

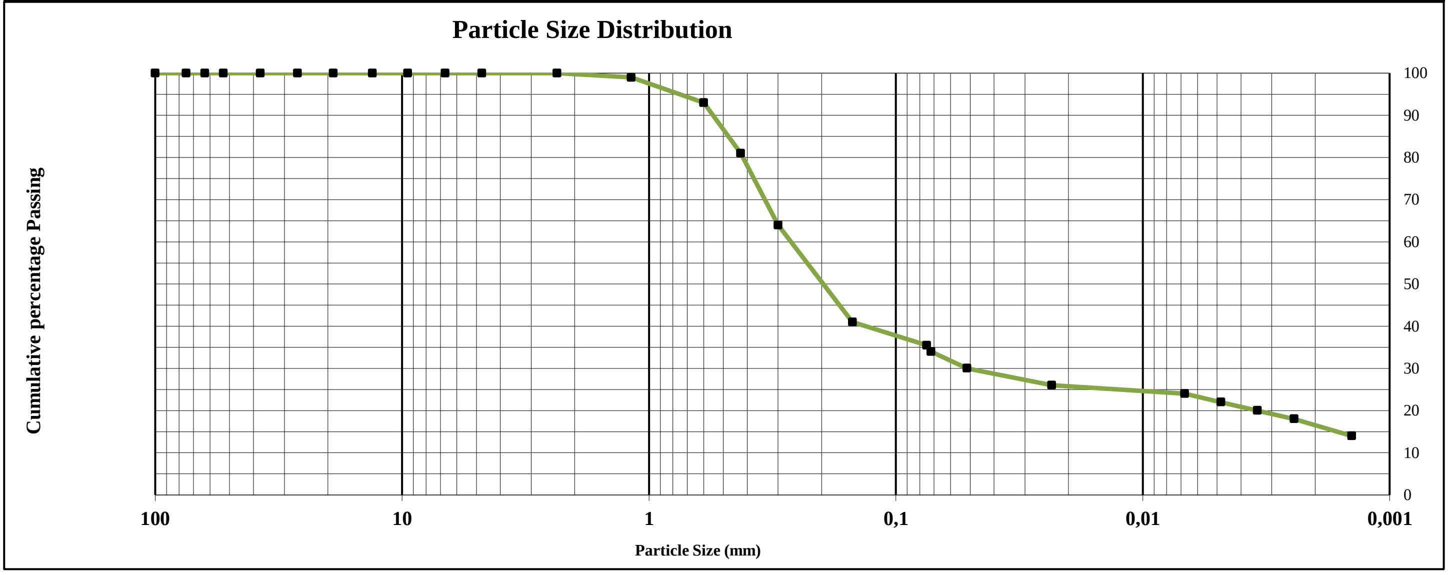
Material Description:	Dark Brown Sand with Pebbles	Sample Number:	13596		
Position:	JD TP10	Liquid Limit	**22,2**	Linear Shrinkage	**1,9**
Depth:	0.0 - 0.7m	Plasticity Index	**4,2**	Insitu M/C%	**10,1**

pH (TMH1 A20)*	**5,8**	**Conductivity s.m-1 (TMH1 A21T)***	**0,002**	**COLTO SPEC**	**G10**

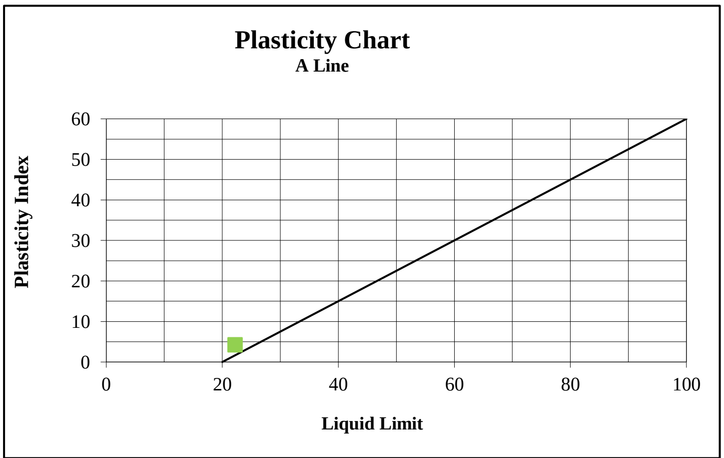
SIEVE ANALYSIS (TMH 1 A1a)*																**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,072	0,051	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	100	100	99	93	81	64	41	35,5	34	30	26	24	22	20	18	14

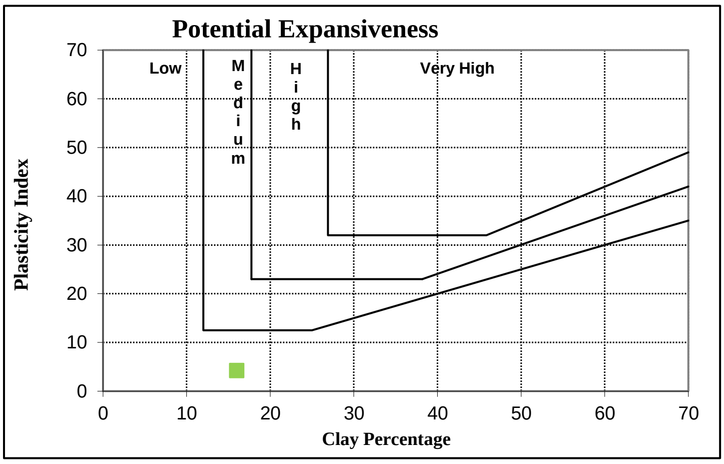
% Passing

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)	1985	9,3	0,0	4	3	3	2	2	1



% Gravel		**% Sand**	68	**% Silt**	16	**% Clay**	16





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	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

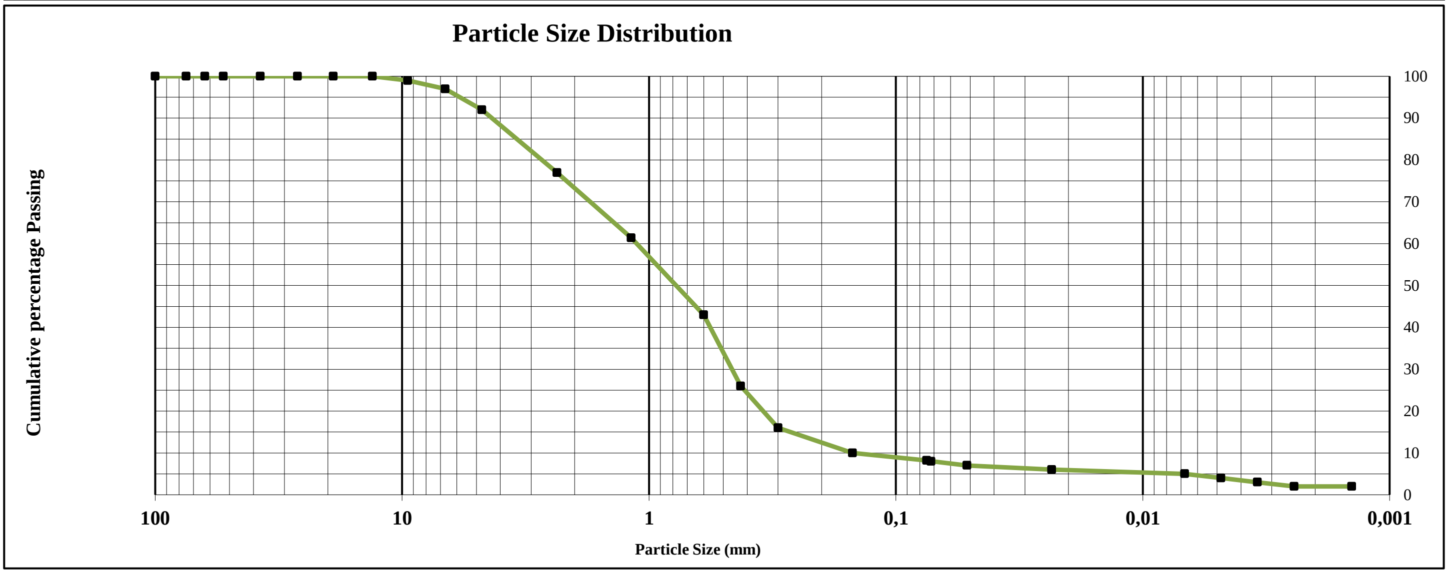
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Dark Brown ReddishSilty Soil with Quartzitic Sandstone	Sample Number:	13597		
Position:	JD TP11	Liquid Limit	**NP**	Linear Shrinkage	**0,0**
Depth:	0.1 - 0.9m	Plasticity Index	**NP**	Insitu M/C%	**4,7**

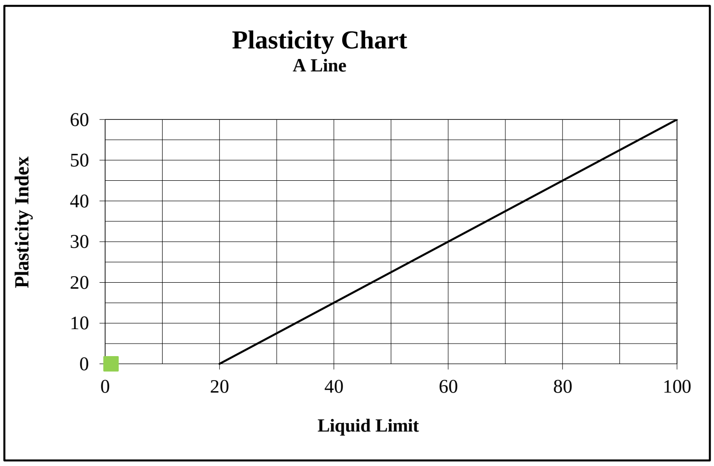
PH (TMH1 A20)*	-	**(TMH1 A21T)* Conductivity $s.m^{-1}$**	-	**COLTO SPEC**	

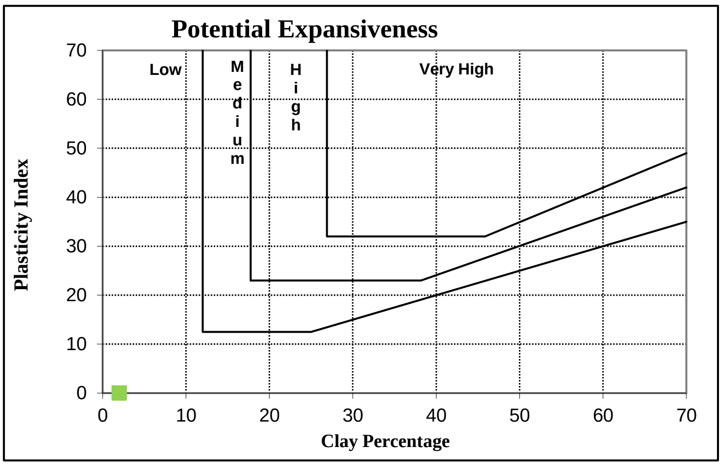
SIEVE ANALYSIS (TMH 1 A1a)*																**HYDROMETER ASTM D422**							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,072	0,051	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	99	97	92	77	61,4	43	26	16	10	8,2	8	7	6	5	4	3	2	2
% Passing																									

MOD AASHTO SANS 3001 GR30		**CBR SANS 3001 GR40**							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel	28	**% Sand**	65	**% Silt**	5	**% Clay**	2





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	1 Century City Drive	Date Received :	20.07.20
	Century City	Date Reported :	31.07.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

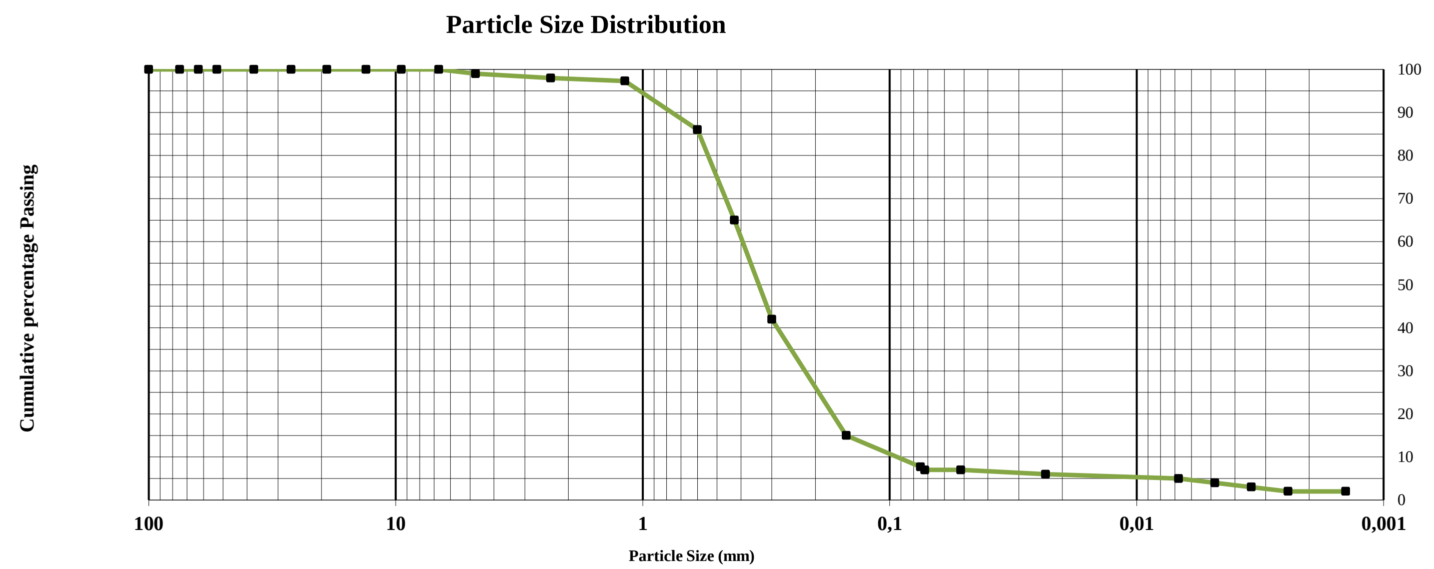
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Light Brown Sand	Sample Number:	13598		
Position:	JD TP12	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.0 - 0.5m	Plasticity Index	**NP**	Insitu M/C%	**7,1**

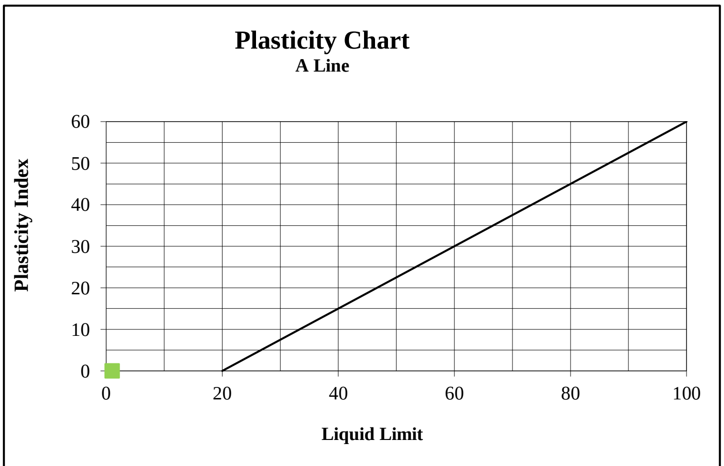
PH (TMH1 A20)*	-		**(TMH1 A21T)* Conductivity s.m^{-1}**	-		**COLTO SPEC**	

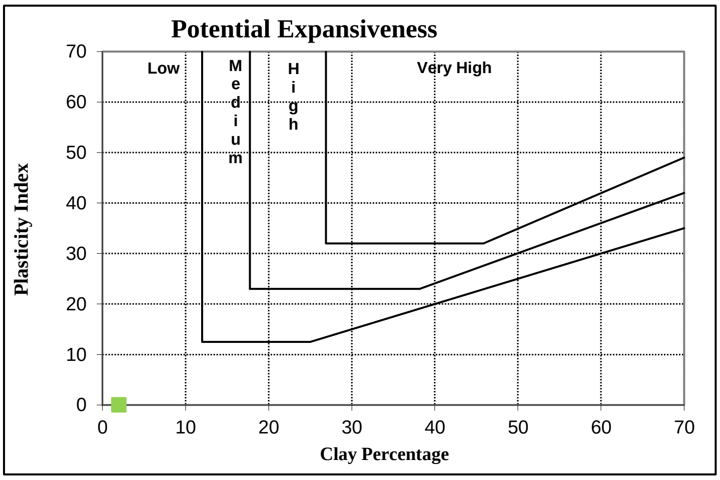
SIEVE ANALYSIS (TMH 1 A1a)*																	HYDROMETER ASTM D422							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,072	0,051	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	99	98	97,3	86	65	42	15	7,7	7	7	6	5	4	3	2	2
% Passing																									

MOD AASHTO SANS 3001 GR30		CBR SANS 3001 GR40							
OMC%		**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)									



% Gravel	2	% Sand	91	% Silt	5	% Clay	2





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	1 Century City Drive	Date Received :	20.07.20
	Century City	Date Reported :	31.07.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

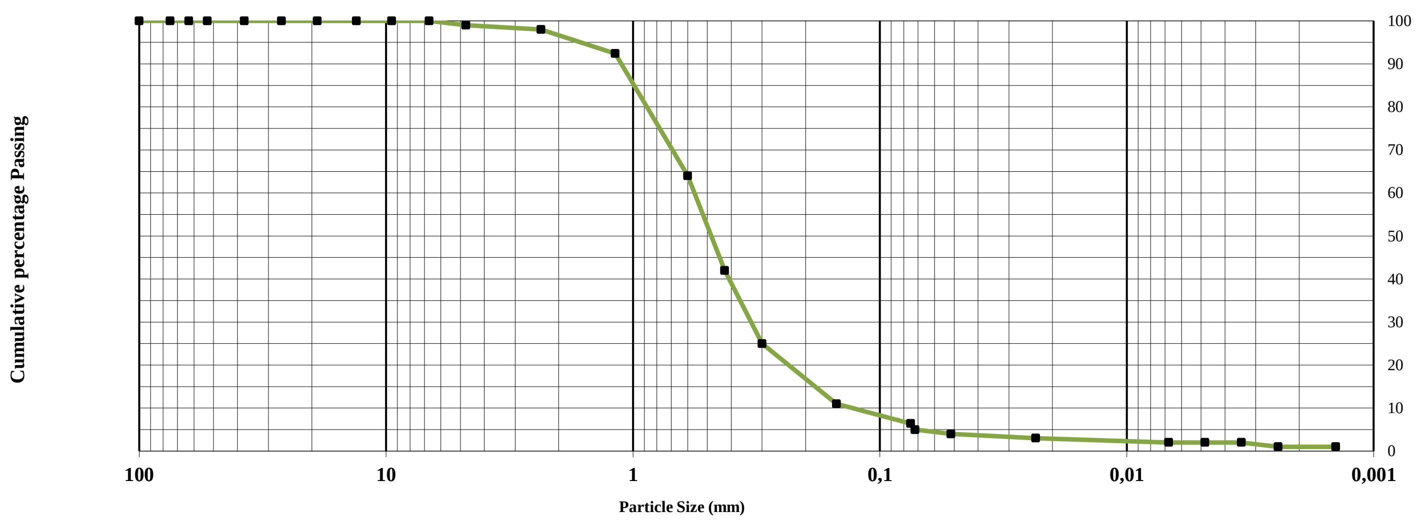
Material Description:	Light Brown Sand	Sample Number:	13599		
Position:	JD TP14	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.0 - 1.6m	Plasticity Index	**NP**	Insitu M/C%	**5,5**

PH (TMH1 A20)*	-	(TMH1 A21T)* Conductivity s.m^{-1}	-	COLTO SPEC	

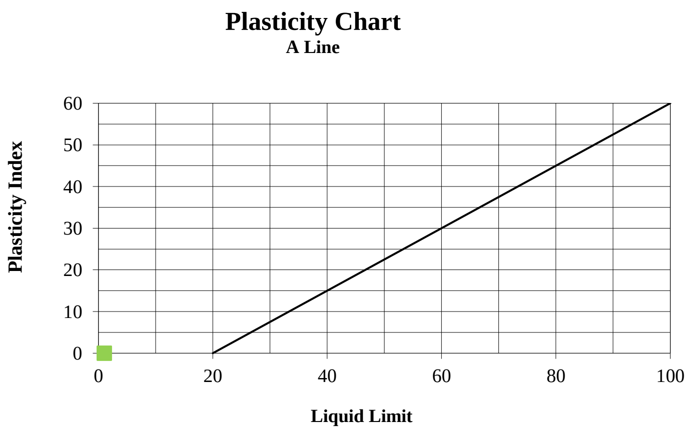
SIEVE ANALYSIS (TMH 1 A1a)*																		HYDROMETER ASTM D422							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,072	0,051	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	100	100	99	98	92,4	64	42	25	11	6,4	5	4	3	2	2	2	1	1
% Passing																									

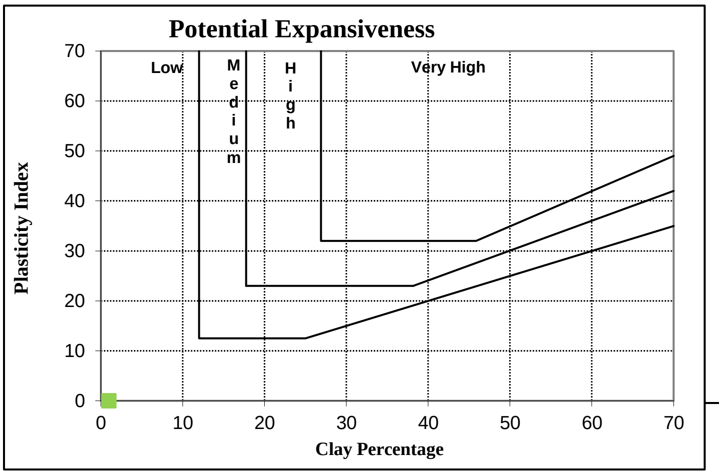
MOD AASHTO SANS 3001 GR30		CBR SANS 3001 GR40							
OMC%		COMP MC	% SWELL	100%	98%	97%	95%	93%	90%
MDD(KG/M^3)									

Particle Size Distribution



% Gravel	4	% Sand	92	% Silt	3	% Clay	1





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Client: **Zutari**
Project: Jan Dissels
Attention: Ms K Myburgh
Your Ref. No: 113834
Date Reported 31.07.20

TEST REPORT REFERENCE NUMBER / JOB NUMBER : SWL12317

Dear Sir / Madam

Herewith please find the original reports pertaining to the above mentioned project.

Test Requested

3 x FOUNDATION INDICATOR
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:
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	1 Century City Drive	Date Received :	20.07.20
	Century City	Date Reported :	31.07.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

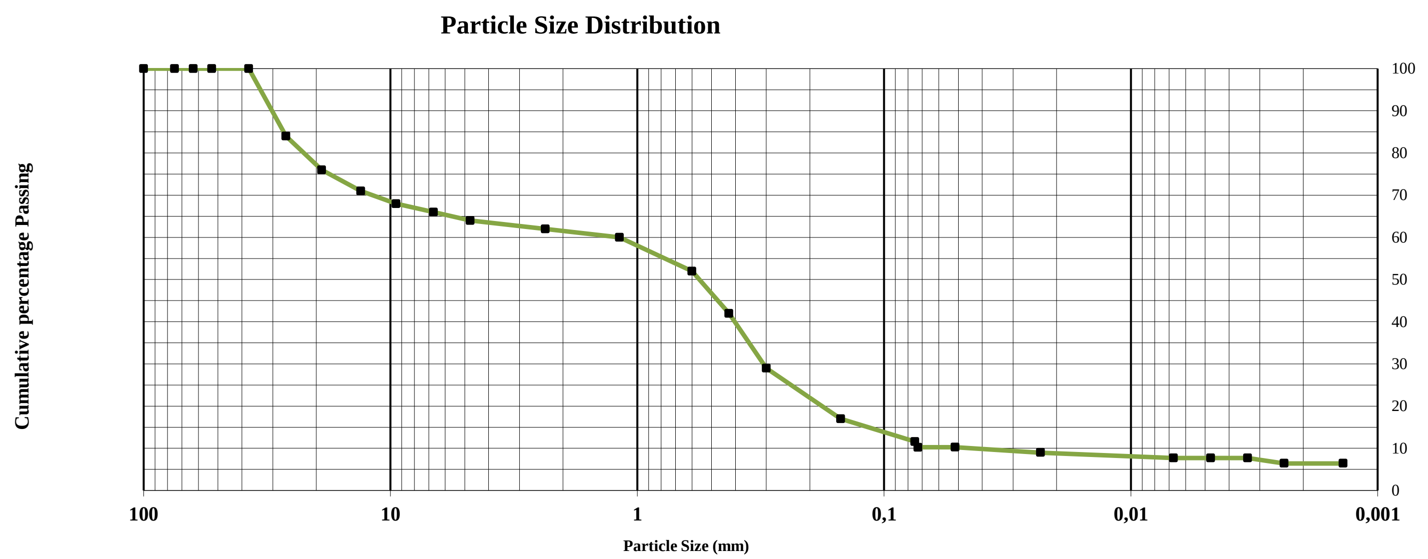
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Dark Brown Reddish Sand with Quartzitic Sandstone	Sample Number:	13600		
Position:	JD TP16	Liquid Limit	NP	Linear Shrinkage	0.0
Depth:	0.0 - 1.4m	Plasticity Index	NP	Insitu M/C%	4,3

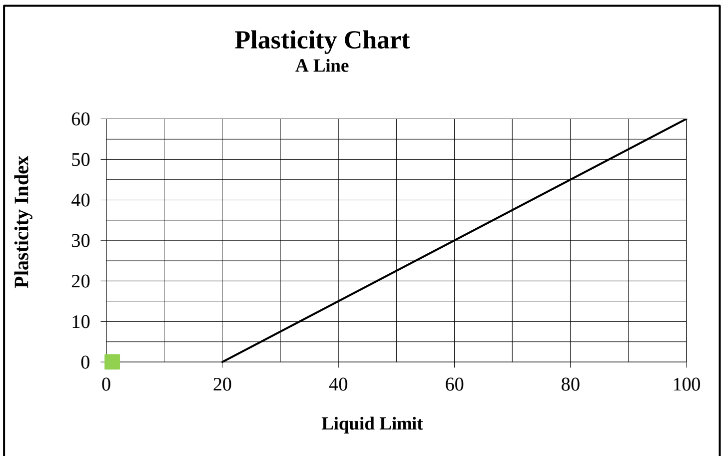
pH (TMH1 A20)*	-	Conductivity s.m-1 (TMH1 A21T)*	-	COLTO SPEC	-

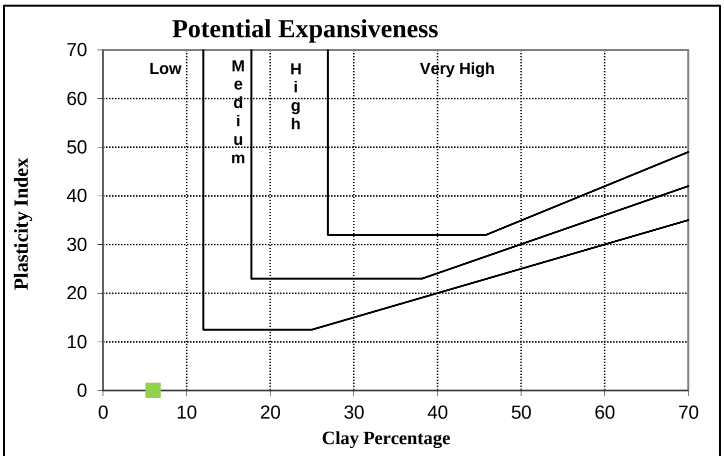
SIEVE ANALYSIS (TMH 1 A1a)*																		HYDROMETER ASTM D422							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,073	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	84	76	71	68	66	64	62	60	52	42	29	17	11,6	10,24	10,24	8,96	7,68	7,68	7,68	6,4	6,4
% Passing																									

MOD AASHTO SANS 3001 GR30		CBR SANS 3001 GR40							
OMC%		COMP MC	% SWELL	100%	98%	97%	95%	93%	90%
MDD(KG/M³)									



% Gravel	39	% Sand	51	% Silt	4	% Clay	6





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	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

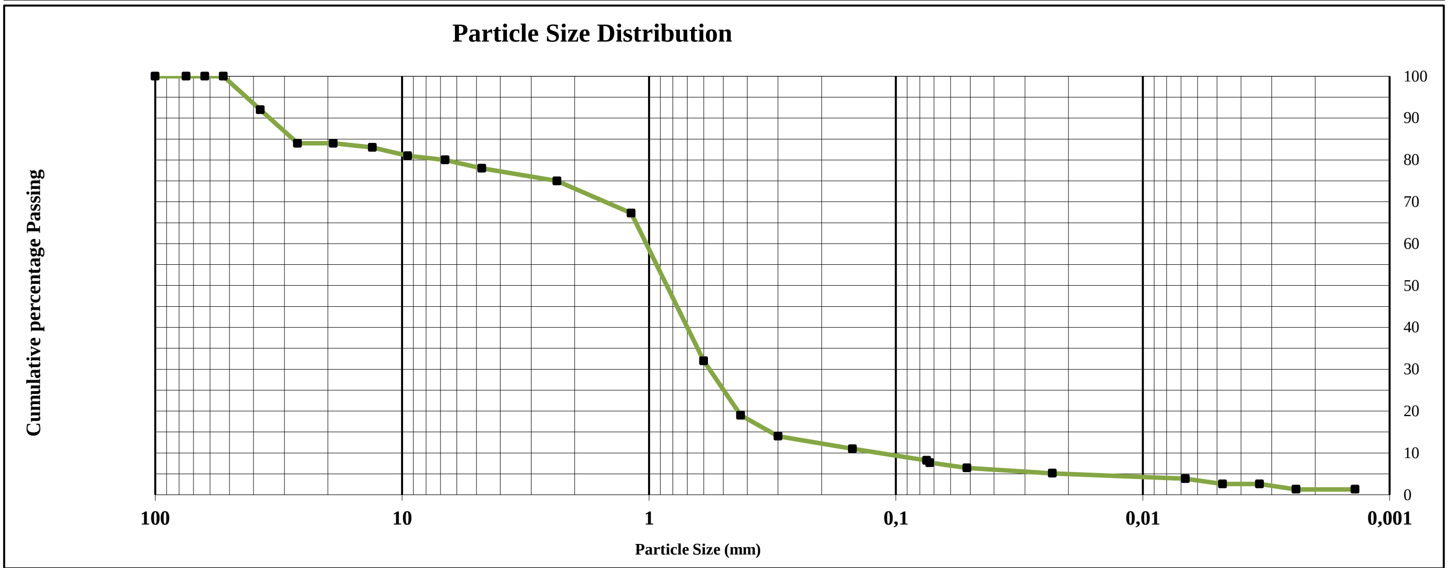
Material Description:	Dark Brown Sand with Quartzitic Sandstone	Sample Number:	13601		
Position:	JD TP21	Liquid Limit	**NP**	Linear Shrinkage	**0,0**
Depth:	0.0 - 0.3m	Plasticity Index	**NP**	Insitu M/C%	**3,8**

PH (TMH1 A20)*	-	**(TMH1 A21T)* Conductivity $s.m^{-1}$**	-	**COLTO SPEC**	-

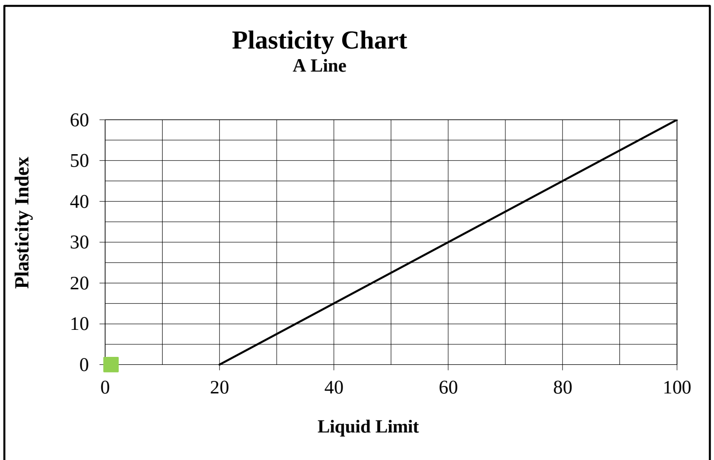
SIEVE ANALYSIS (TMH 1 A1a)*																HYDROMETER ASTM D422							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,073	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	92	84	84	83	81	80	78	75	67,3	32	19	14	11	8,2	7,68	6,4	5,12	3,84	2,56	2,56	1,28	1,28

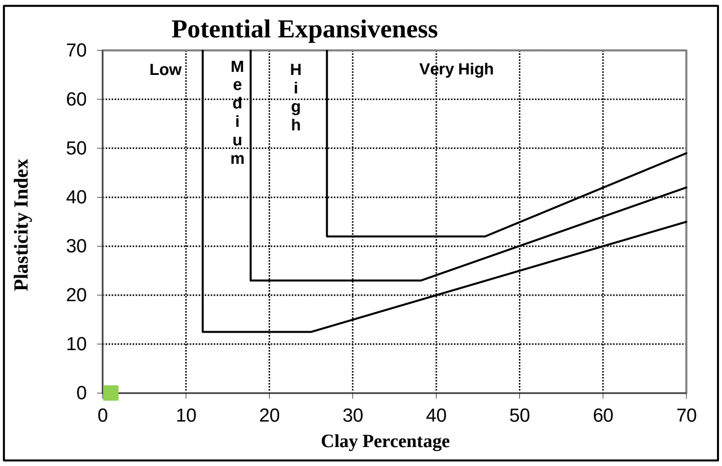
% Passing

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	66	% Silt	6	% Clay	1





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CIVIL ENGINEERING TESTING LABORATORIES

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Customer :	**Zutari**	Project :	Jan Dissels
	1 Century City Drive	Date Received :	20.07.20
	Century City	Date Reported :	31.07.20
	7446	Req. Number :	113834
Attention :	Ms K Myburgh		

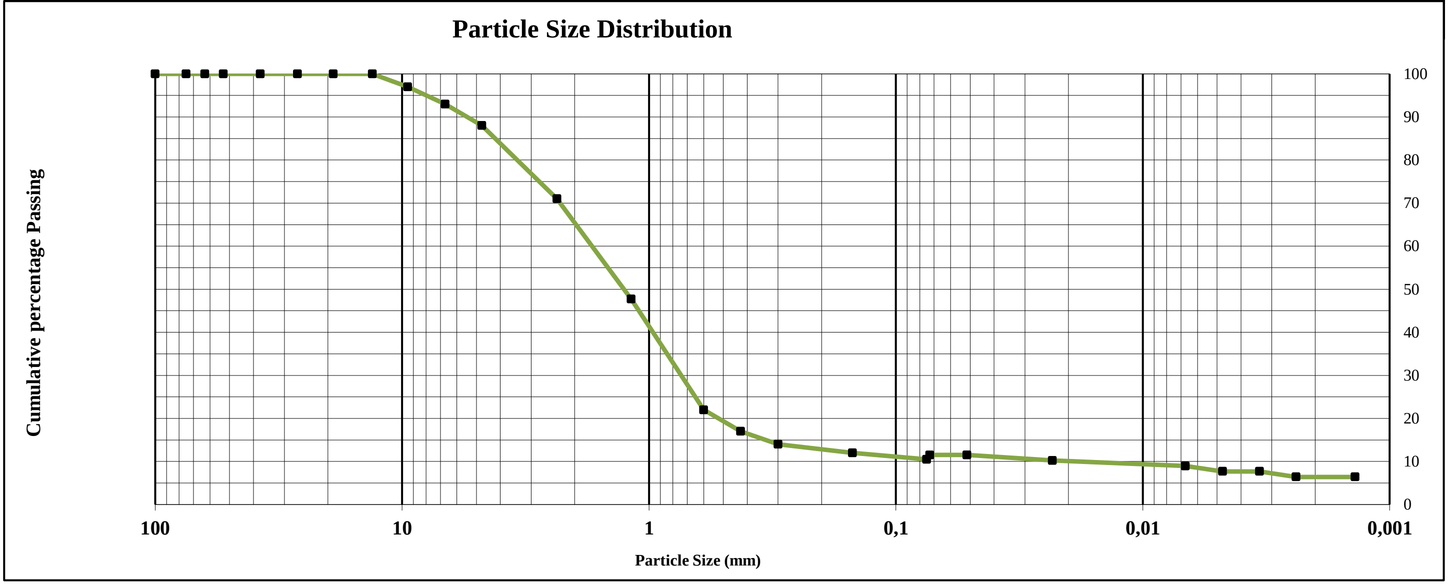
MOD / CBR / FOUNDATION INDICATOR - TMH1 A1* / ASTM D422 / SANS 3001 GR30 / SANS 3001 GR40

Material Description:	Light Reddish Coarse Sand with Quartzitic Sandstone	Sample Number:	13602		
Position:	JD TP22	Liquid Limit	**NP**	Linear Shrinkage	**0.0**
Depth:	0.6 - 1.2m	Plasticity Index	**NP**	Insitu M/C%	**4**

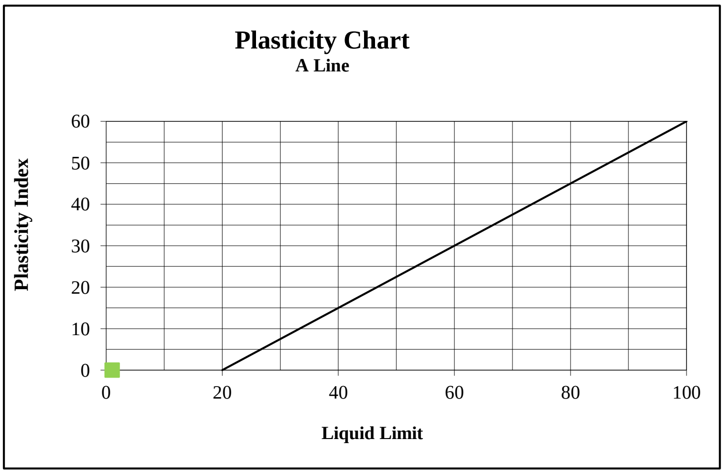
PH (TMH1 A20)*	**4,3**	**(TMH1 A21T)* Conductivity $s.m^{-1}$**	**0,012**	**COLTO SPEC**	**G7**

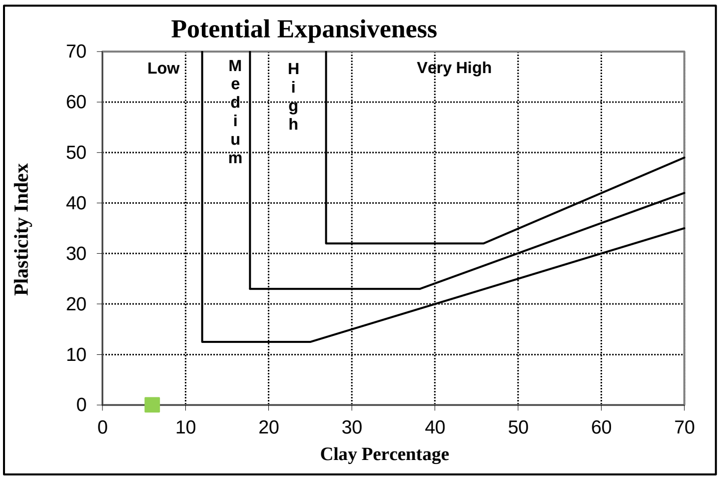
SIEVE ANALYSIS (TMH 1 A1a)*																HYDROMETER ASTM D422							
100	75	63	53	37,5	26,5	19,0	13,2	9,5	6,7	4,75	2,36	1,18	0,60	0,425	0,300	0,150	0,075	0,073	0,052	0,023	0,007	0,005	0,003	0,002	0,001
100	100	100	100	100	100	100	100	97	93	88	71	47,7	22	17	14	12	10,5	11,52	11,52	10,24	8,96	7,68	7,68	6,4	6,4
% Passing																									

MOD AASHTO SANS 3001 GR30		CBR SANS 3001 GR40							
OMC%	8,4	**COMP MC**	**% SWELL**	**100%**	**98%**	**97%**	**95%**	**93%**	**90%**
MDD(KG/M^3)	2168	8	0,0	49	35	30	21	15	9



% Gravel	**36**	**% Sand**	**52**	**% Silt**	**6**	**% Clay**	**6**





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)	114.4	114.4	114.2
Moisture	(%)	8.4	8.4	8.4
Dry Density	(Mg/m^3)	1.87	1.87	1.86
Bulk Density	(Mg/m^3)	2.02	2.02	2.02
Void Ratio		0.393	0.393	0.396
Particle Density	(Mg/m^3)	2.60		
Sample Method		Bag		
Disturbed/Undisturbed		Disturbed		
Remoulded Desity	(Mg/m^3)	2168 (98%)		

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3
Vertical Displacement	(mm)	0.197	0.559	0.760
Void Ratio After Consolidation		0.379	0.354	0.343

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3
Normal Stress	(kPa)	50	100	150
Peak Shear Stress	(kPa)	58.4	98.3	146.4
Horizontal Strain at Failure	(mm)	1.4	2.0	2.5
Verical Stain at Failure	(mm)	-0.202	-0.002	-0.130
Rate of Shear	(mm/min)	0.026	0.027	0.026
Friction Angle (ϕ)	(°)	41.3		
Cohesion (c)	(kPa)	13.14		

Final Sample Details

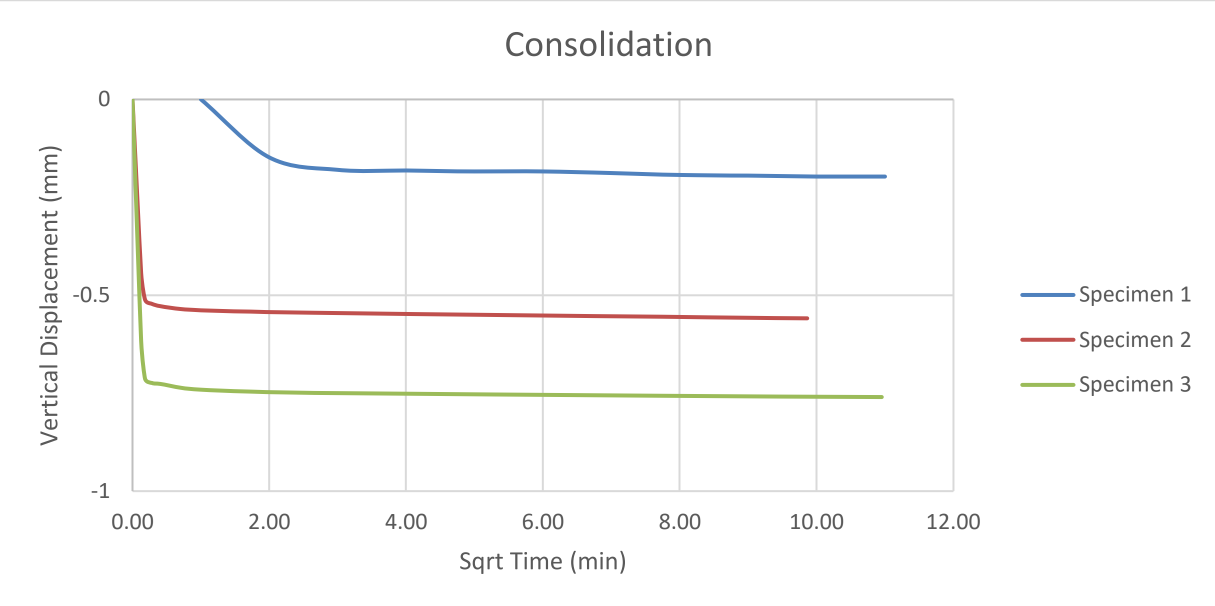
		Specimen 1	Specimen 2	Specimen 3
Mass	(g)	117.5	119.1	118.8
Moisture	(%)	18.2	17.0	16.4
Void Ratio		0.394	0.354	0.352

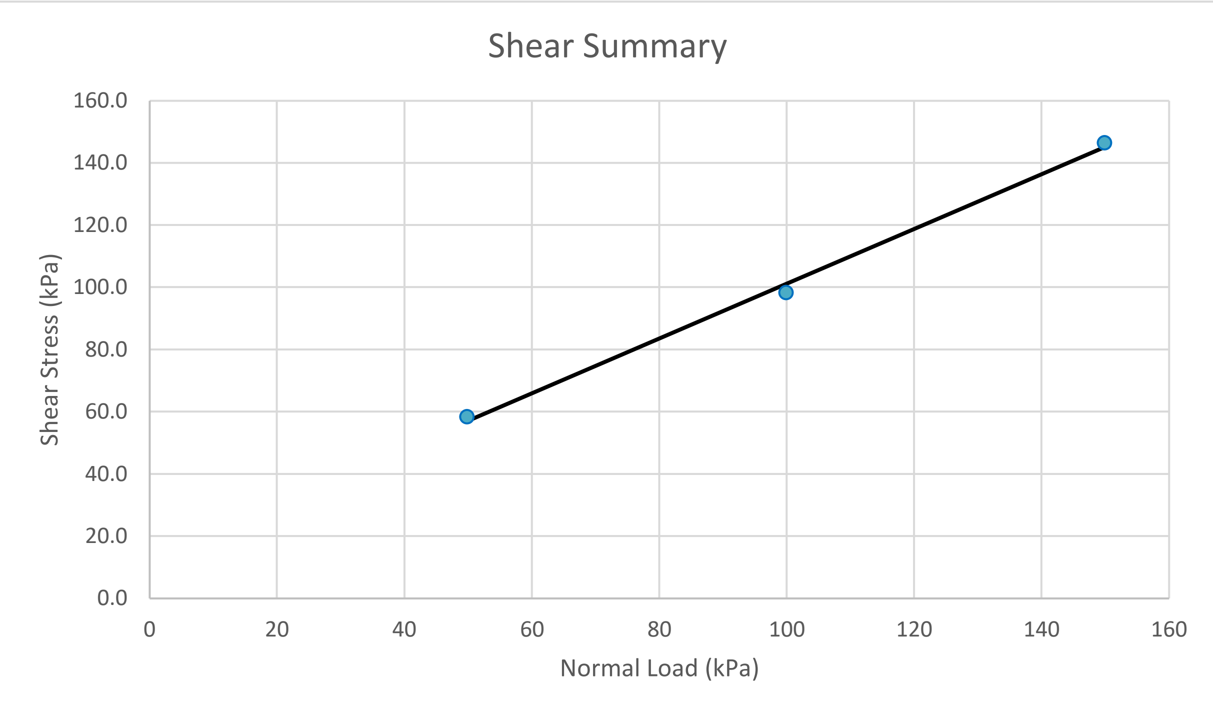
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	03/08/2020
	Jobfile	SWG00088	Sample	JD_TP22_0.6-1.2m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	41.3
Cohesion (c)	(kPa)	13.14



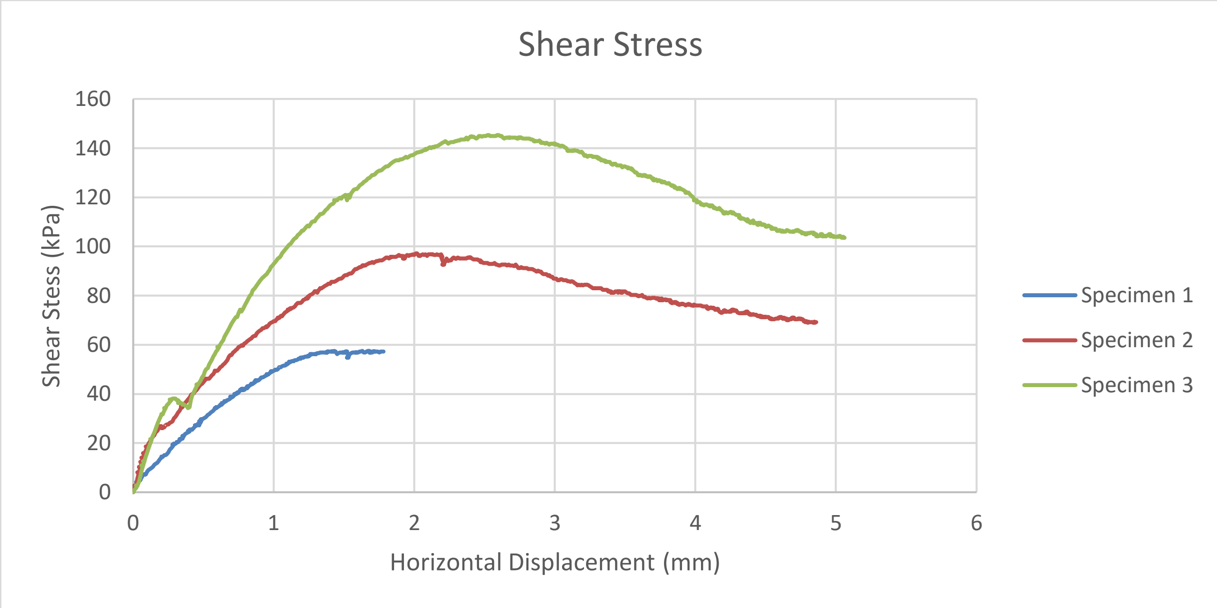


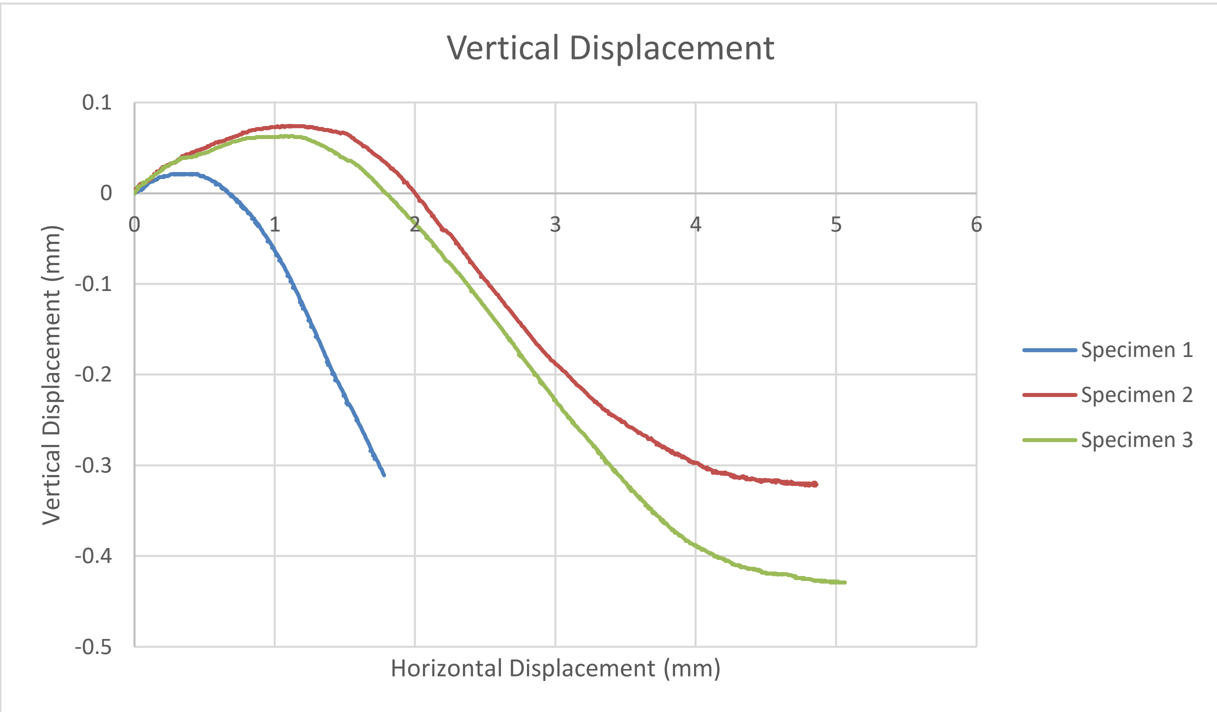
STEYN-WILSON GEOTECHNICAL	Test Method BS1377 - 7: 1990		Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech
	Site Reference Jobfile SWG00088 Client Zutari		Test Date 03/08/2020 Sample JD_TP22_0.6-1.2m Borehole Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	41.3
Cohesion (c)	(kPa)	13.14





STEYN-WILSON GEOTECHNICAL	Test Method BS1377 - 7: 1990		Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech
	Site Reference		Test Date 03/08/2020
	Jobfile	SWG00088	Sample JD_TP22_0.6-1.2m
	Client	Zutari	Borehole Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC

Direct Shear Test

Initial Sample Details

		Specimen 1	Specimen 2	Specimen 3	Specimen 4
Height	(mm)	20.0	20.0	20.0	20.0
Diameter	(mm)	60.0	60.0	60.0	60.0
Mass	(g)	117.8	117.8	117.8	117.3
Moisture	(%)	11.2	11.2	11.2	11.2
Dry Density	(Mg/m^3)	1.87	1.87	1.87	1.87
Bulk Density	(Mg/m^3)	2.08	2.08	2.08	2.07
Void Ratio		0.415	0.415	0.415	0.421
Particle Density	(Mg/m^3)	2.65			
Sample Method		Bag			
Disturbed/Undisturbed		Disturbed			
Remoulded Desity	(Mg/m^3)	1926 (98%)			

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3	Specimen 4
Vertical Displacement	(mm)	0.068	0.143	0.505	0.403
Void Ratio After Consolidation		0.410	0.404	0.379	0.392

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3	Specimen 4
Normal Stress	(kPa)	25	50	150	100
Peak Shear Stress	(kPa)	32.2	48.5	151.4	111.8
Horizontal Strain at Failure	(mm)	1.4	1.9	2.0	1.8
Verical Stain at Failure	(mm)	-0.179	-0.186	-0.115	-0.069
Rate of Shear	(mm/min)	0.020	0.018	0.019	0.016
Friction Angle (ϕ)	(°)	44.7			
Cohesion (c)	(kPa)	4.61			

Final Sample Details

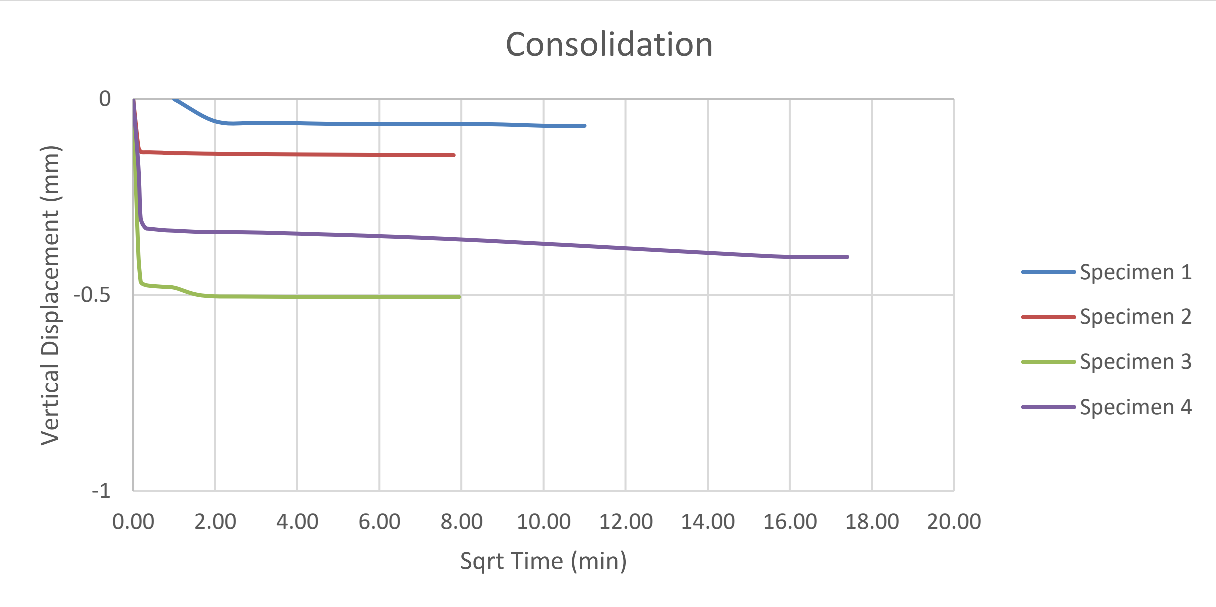
		Specimen 1	Specimen 2	Specimen 3	Specimen 4
Mass	(g)	118.6	116.5	117.8	118.3
Moisture	(%)	15.4	15.3	15.0	15.2
Void Ratio		0.422	0.418	0.387	0.397

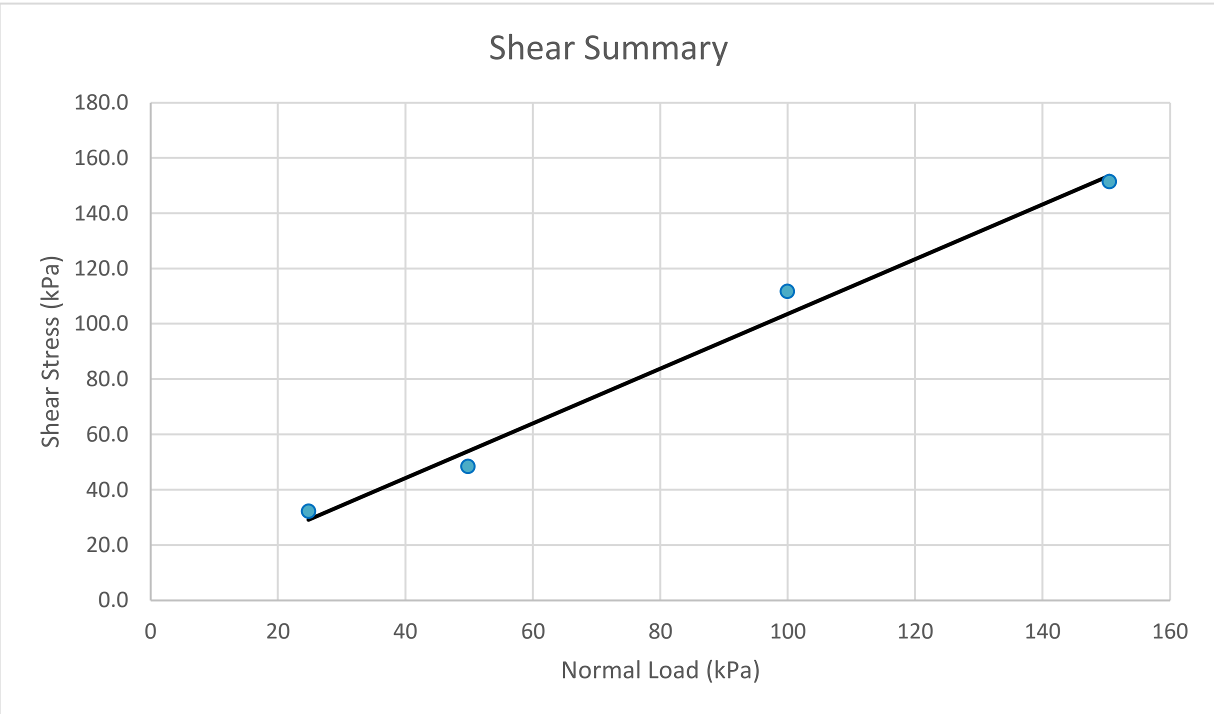
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	27/07/2020
	Jobfile	SWG00088	Sample	JD_TP04_0.0-0.4m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	44.7
Cohesion (c)	(kPa)	4.61



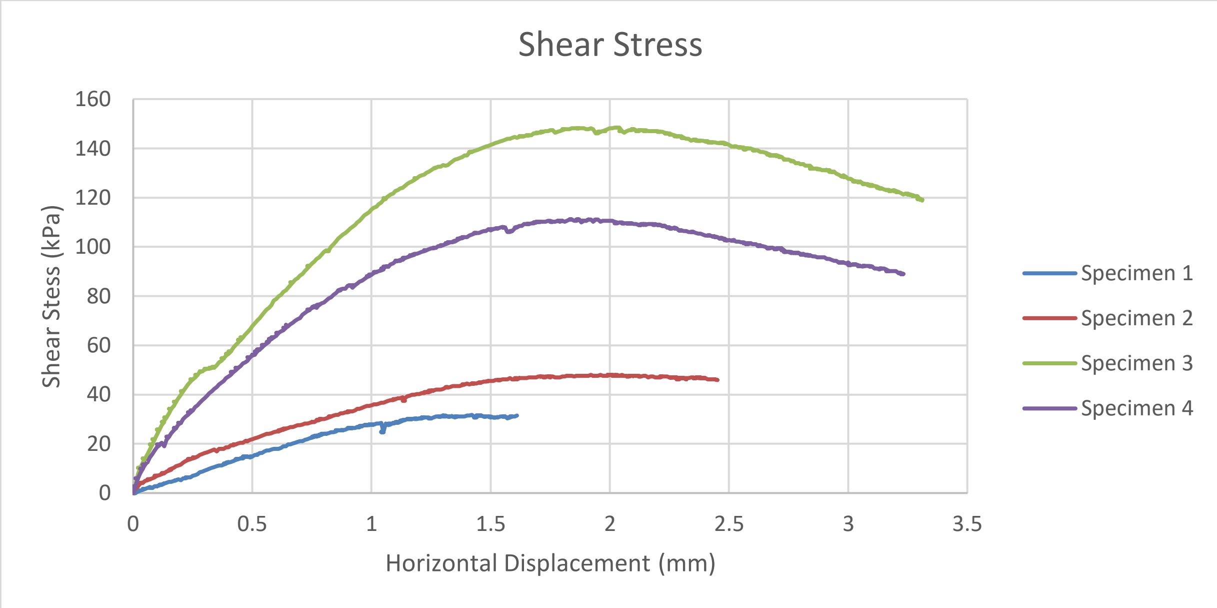


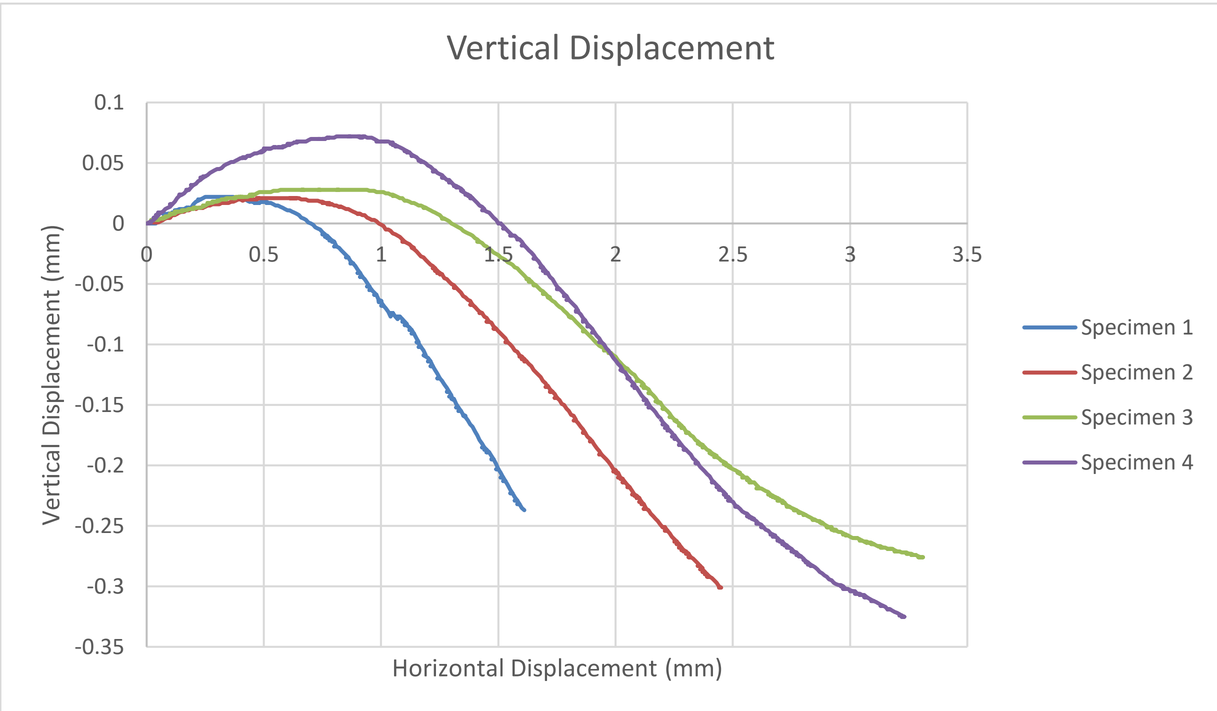
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	27/07/2020
	Jobfile	SWG00088	Sample	JD_TP04_0.0-0.4m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	44.7
Cohesion (c)	(kPa)	4.61





STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech
	Site Reference Jobfile SWG00088 Client Zutari		Test Date 27/07/2020 Sample JD_TP04_0.0-0.4m 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)	130.4	130.1	130.8
Moisture	(%)	8.3	8.3	8.3
Dry Density	(Mg/m^3)	2.13	2.12	2.14
Bulk Density	(Mg/m^3)	2.31	2.30	2.31
Void Ratio		0.226	0.229	0.222
Particle Density	(Mg/m^3)	2.61		
Sample Method		Bag		
Disturbed/Undisturbed		Disturbed		
Remoulded Desity	(Mg/m^3)	2170 (98%)		

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3
Vertical Displacement	(mm)	0.175	0.169	0.852
Void Ratio After Consolidation		0.215	0.218	0.170

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3
Normal Stress	(kPa)	25	50	150
Peak Shear Stress	(kPa)	35.4	68.6	147.1
Horizontal Strain at Failure	(mm)	1.9	1.6	3.8
Verical Stain at Failure	(mm)	-0.176	-0.365	0.108
Rate of Shear	(mm/min)	0.026	0.020	0.022
Friction Angle (ϕ)	(°)	43.5		
Cohesion (c)	(kPa)	13.00		

Final Sample Details

		Specimen 1	Specimen 2	Specimen 3
Mass	(g)	126.1	130.7	131.0
Moisture	(%)	17.0	13.9	14.1
Void Ratio		0.226	0.241	0.163

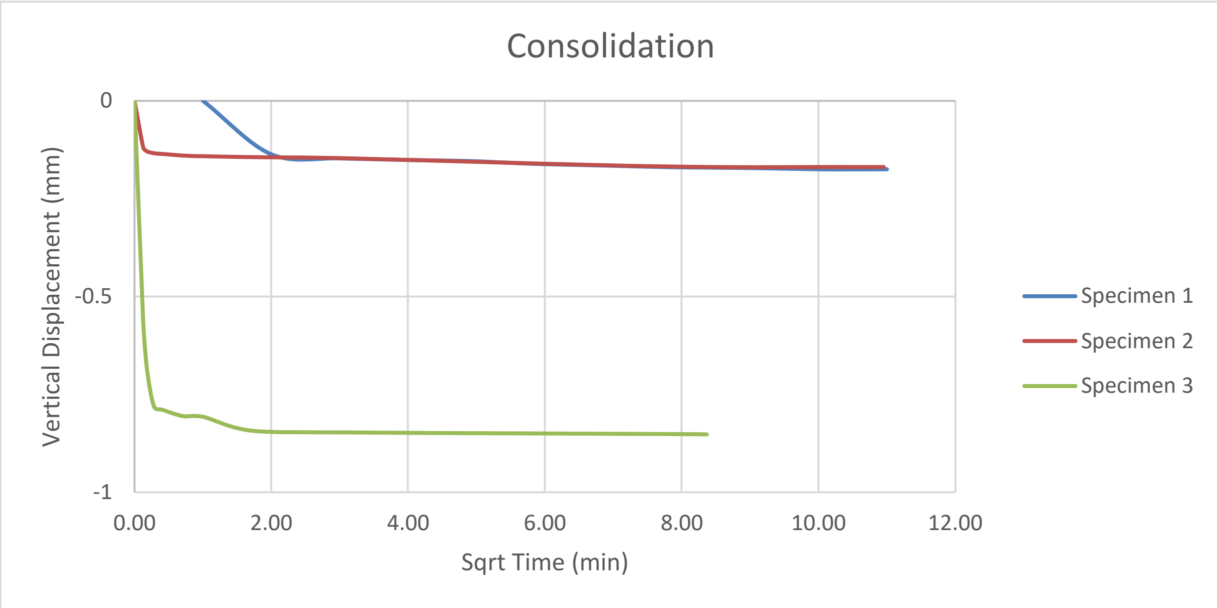
Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
Site Reference		Test Date	30/07/2020
Jobfile	SWG00088	Sample	JD_TP05_0.2-0.7m
Client	Zutari	Borehole	Clanwilliam Bridging Study
Operator:FC	Checked: FC	Approved: FC	

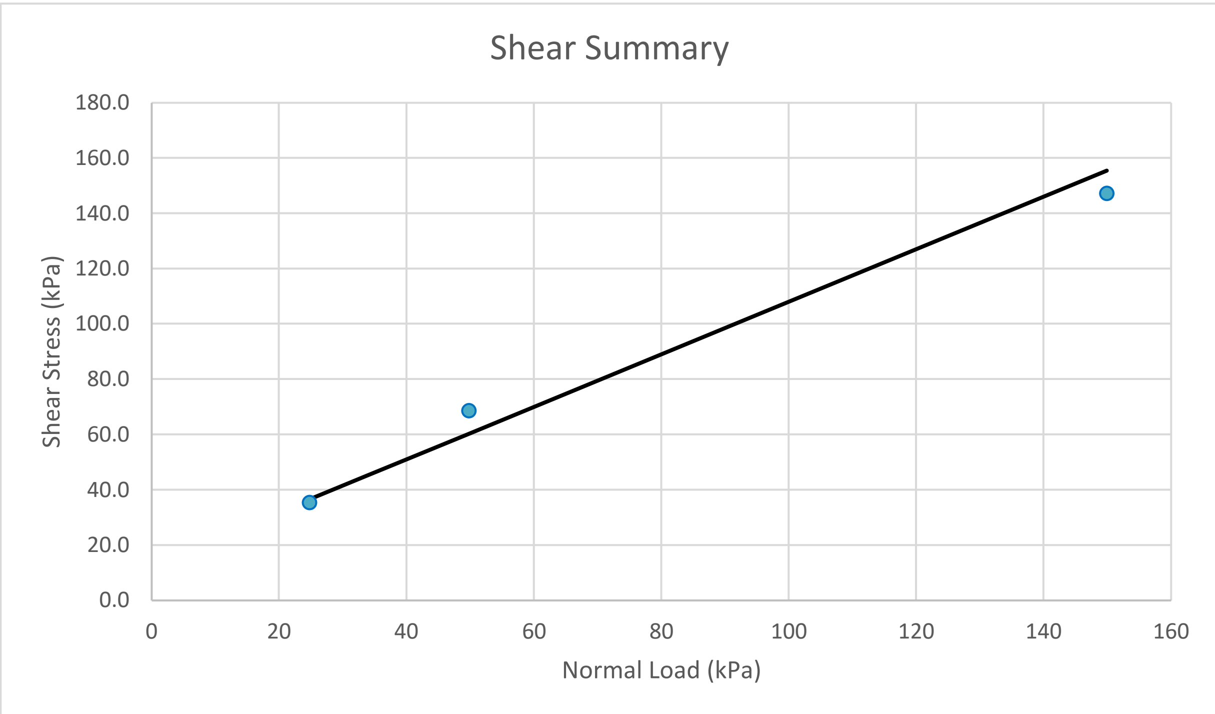
STEYN-WILSON GEOTECHNICAL

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	43.5
Cohesion (c)	(kPa)	13.00



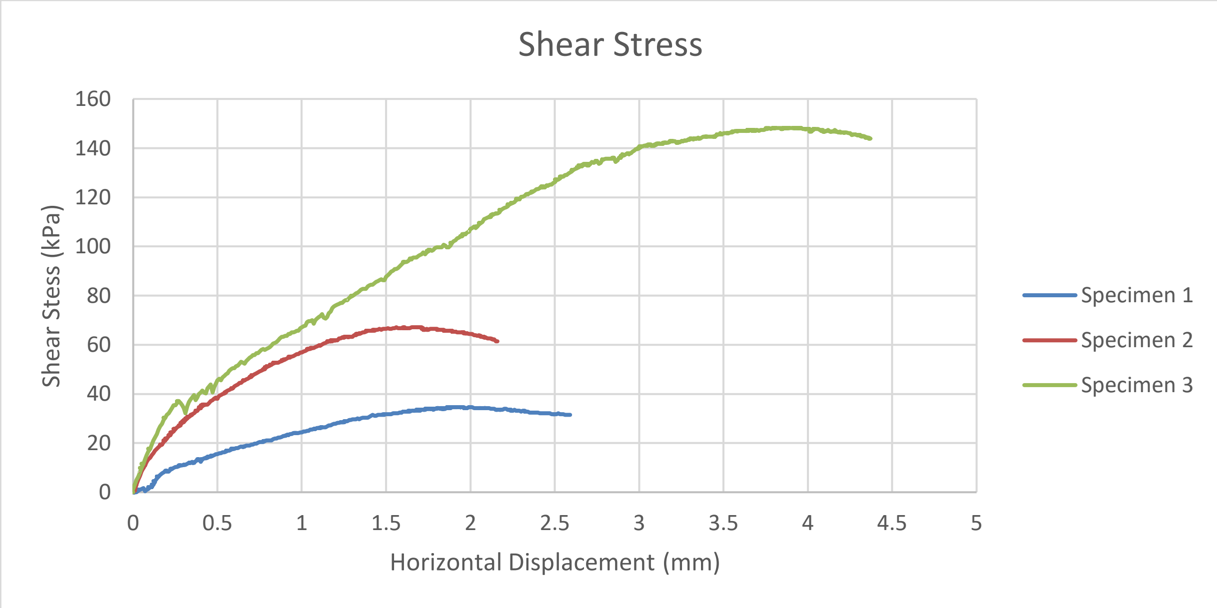


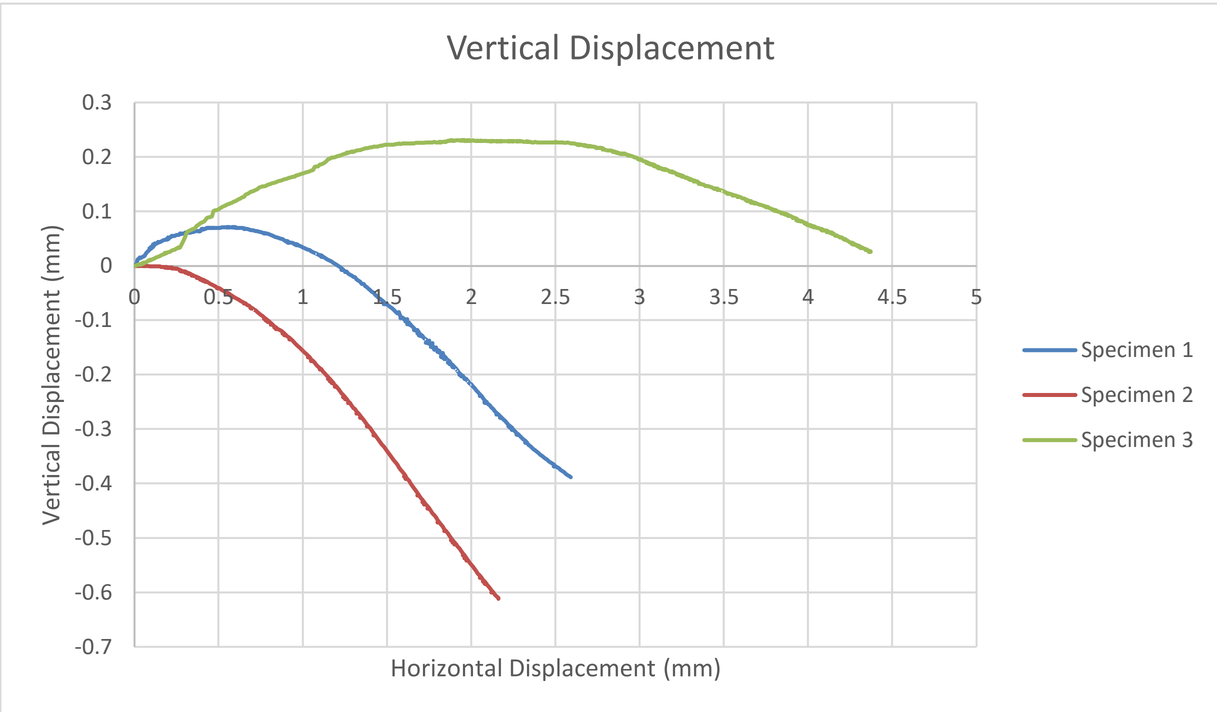
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	30/07/2020
	Jobfile	SWG00088	Sample	JD_TP05_0.2-0.7m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	43.5
Cohesion (c)	(kPa)	13.00





STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	30/07/2020
	Jobfile	SWG00088	Sample	JD_TP05_0.2-0.7m
	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)	115.1	115.7	115.5
Moisture	(%)	13.1	13.1	13.1
Dry Density	(Mg/m^3)	1.80	1.81	1.81
Bulk Density	(Mg/m^3)	2.04	2.05	2.04
Void Ratio		0.439	0.432	0.434
Particle Density	(Mg/m^3)	2.59		
Sample Method		Bag		
Disturbed/Undisturbed		Disturbed		
Remoulded Desity	(Mg/m^3)	1806 (98%)		

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3
Vertical Displacement	(mm)	0.320	0.606	0.758
Void Ratio After Consolidation		0.416	0.388	0.380

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3
Normal Stress	(kPa)	51	100	150
Peak Shear Stress	(kPa)	48.5	89.1	137.9
Horizontal Strain at Failure	(mm)	1.9	2.1	1.9
Verical Stain at Failure	(mm)	-0.065	-0.056	-0.119
Rate of Shear	(mm/min)	0.026	0.026	0.025
Friction Angle (ϕ)	(°)	42.1		
Cohesion (c)	(kPa)	1.12		

Final Sample Details

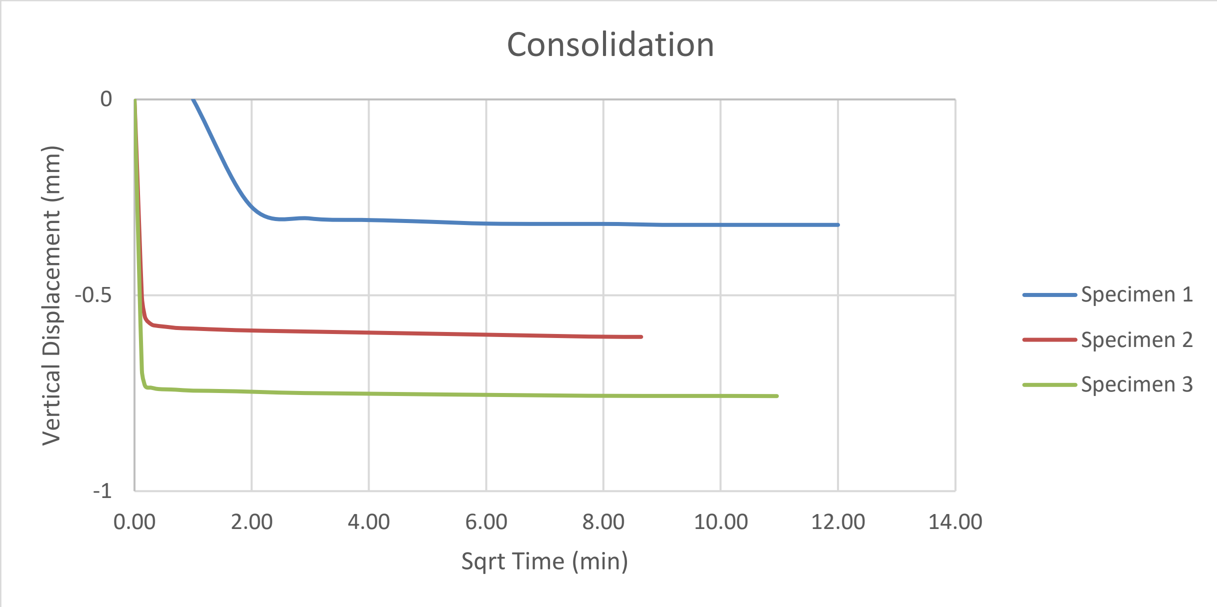
		Specimen 1	Specimen 2	Specimen 3
Mass	(g)	111.2	117.1	116.6
Moisture	(%)	18.6	18.4	16.7
Void Ratio		0.421	0.392	0.388

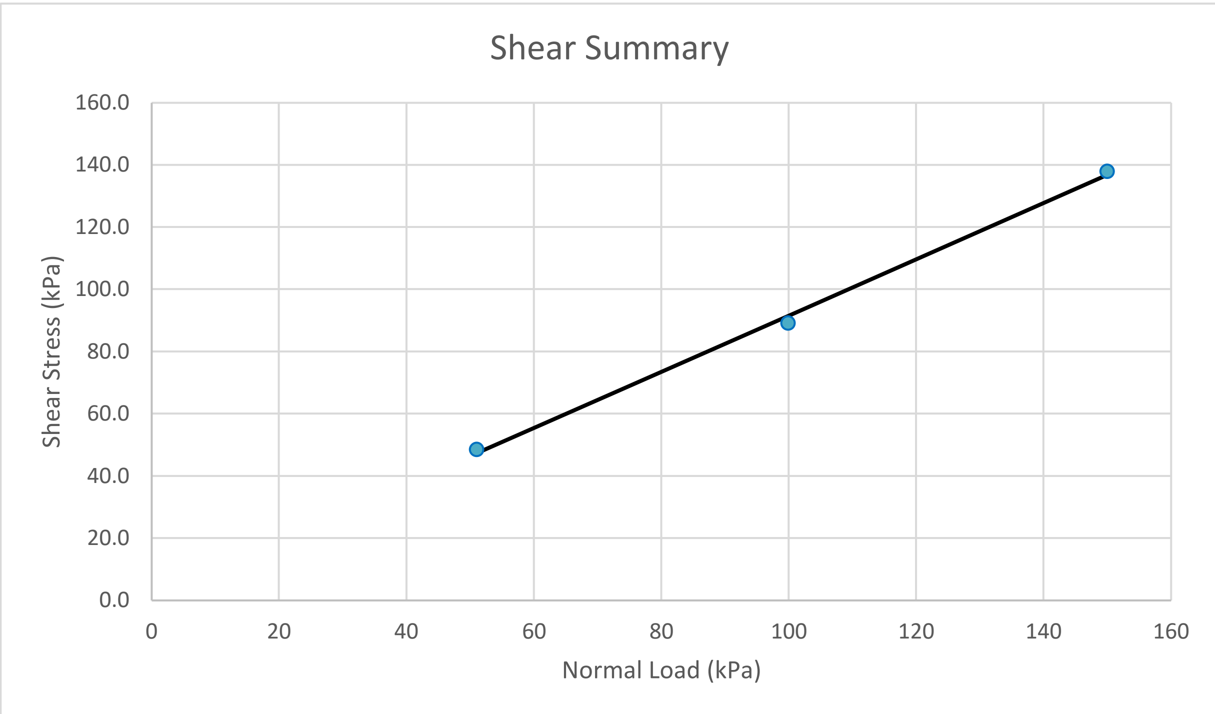
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech
	Site Reference Jobfile SWG00088 Client Zutari		Test Date 31/07/2020 Sample JD_TP09_0.0-1.1m Borehole Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	42.1
Cohesion (c)	(kPa)	1.12



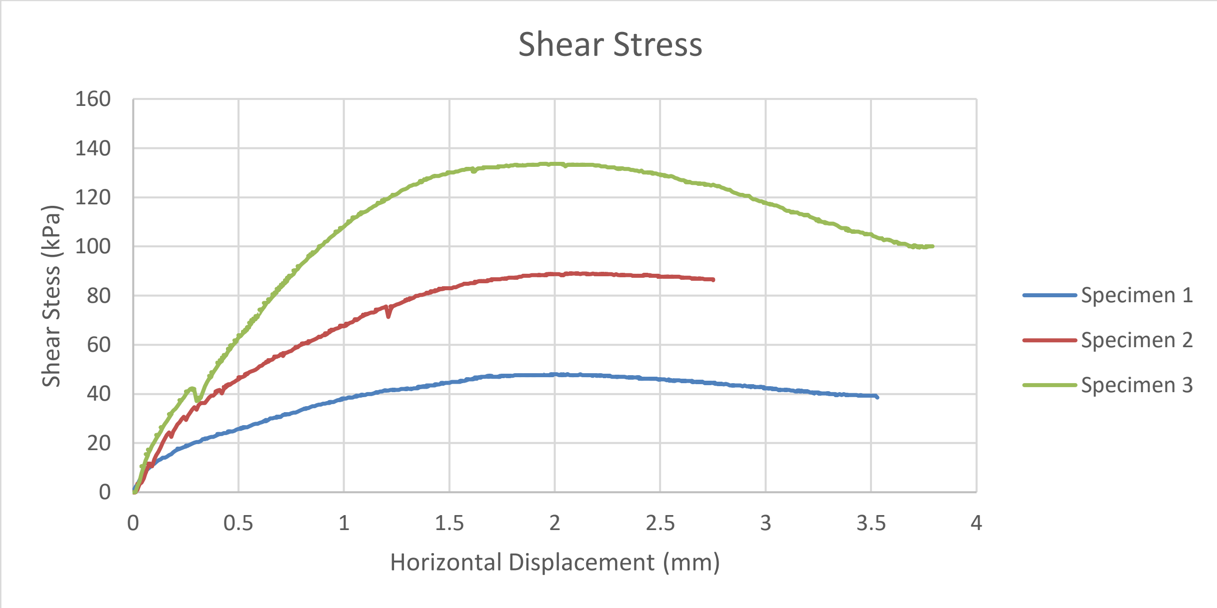


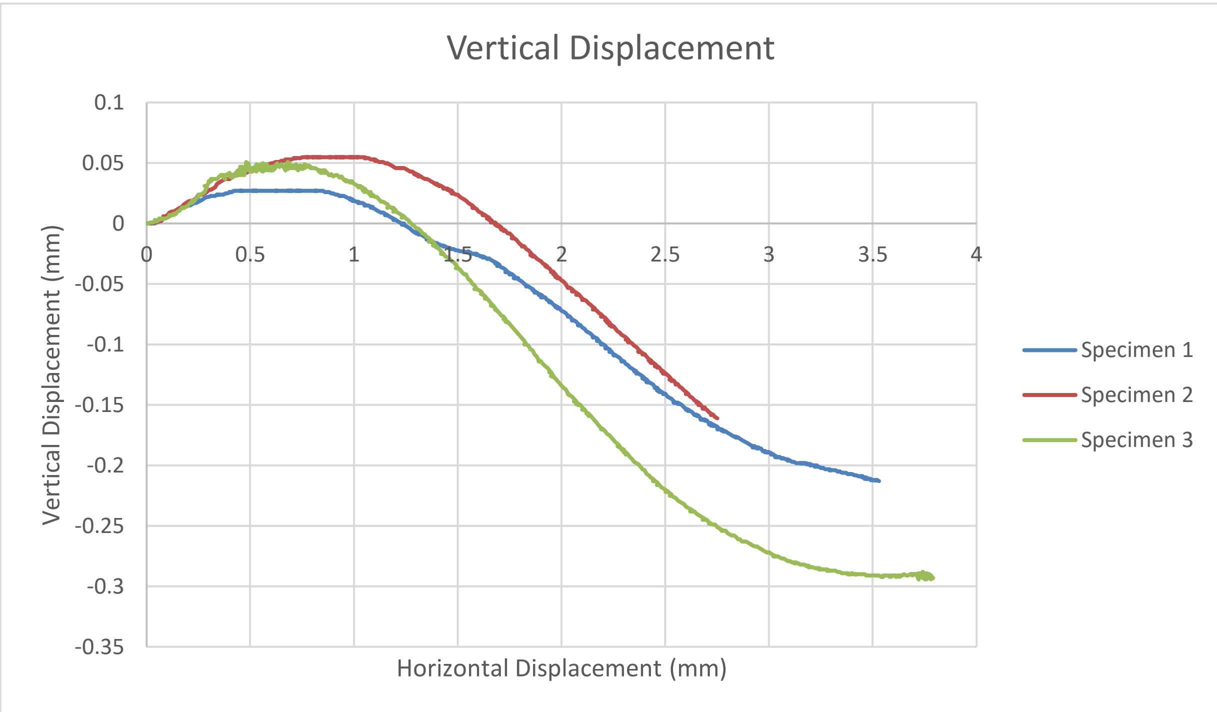
STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech
	Site Reference		Test Date 31/07/2020
	Jobfile	SWG00088	Sample JD_TP09_0.0-1.1m
	Client	Zutari	Borehole Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	42.1
Cohesion (c)	(kPa)	1.12





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	Site Reference Jobfile SWG00088 Client Zutari		Test Date 31/07/2020 Sample JD_TP09_0.0-1.1m 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)	120.7	120.6	120.5
Moisture	(%)	9.6	9.6	9.6
Dry Density	(Mg/m^3)	1.95	1.95	1.94
Bulk Density	(Mg/m^3)	2.13	2.13	2.13
Void Ratio		0.335	0.336	0.337
Particle Density	(Mg/m^3)		2.60	
Sample Method			Bag	
Disturbed/Undisturbed			Disturbed	
Remoulded Desity	(Mg/m^3)		1985 (98%)	

Consolidation Details

		Specimen 1	Specimen 2	Specimen 3
Vertical Displacement	(mm)	0.766	1.840	1.972
Void Ratio After Consolidation		0.284	0.213	0.205

Maximum Shear Stress Results

		Specimen 1	Specimen 2	Specimen 3
Normal Stress	(kPa)	50	100	150
Peak Shear Stress	(kPa)	37.8	60.1	83.1
Horizontal Strain at Failure	(mm)	2.5	3.3	4.9
Verical Stain at Failure	(mm)	0.323	0.347	0.423
Rate of Shear	(mm/min)	0.008	0.014	0.018
Friction Angle (ϕ)	(°)		24.3	
Cohesion (c)	(kPa)		15.20	

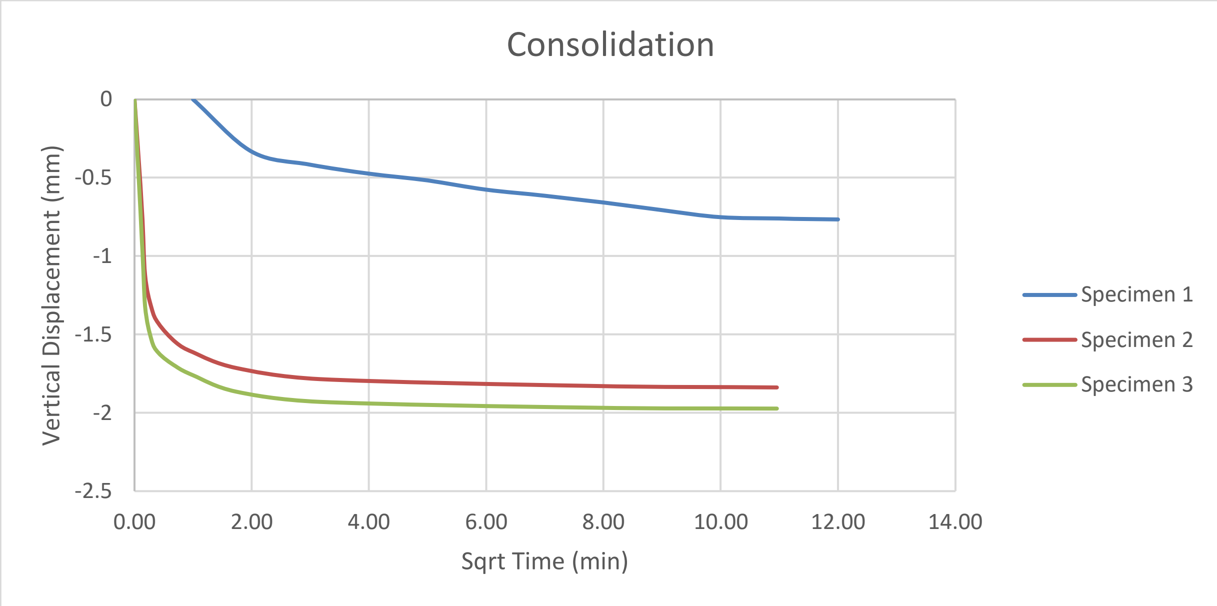
Final Sample Details

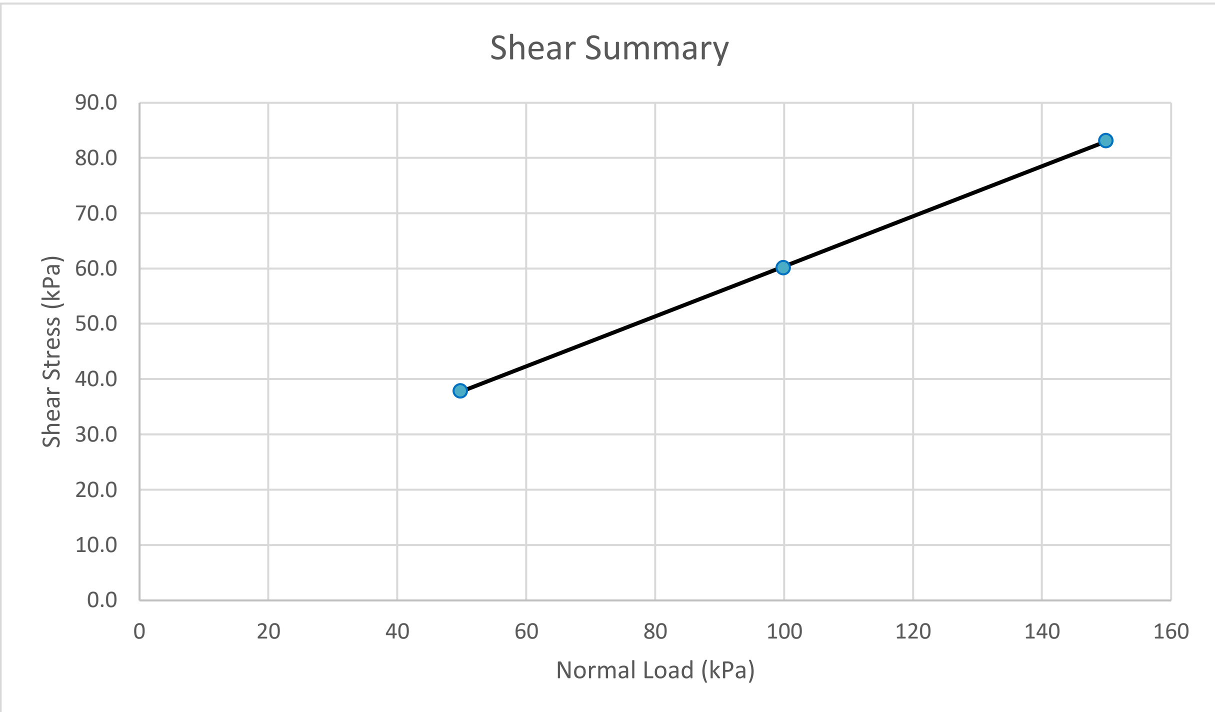
		Specimen 1	Specimen 2	Specimen 3
Mass	(g)	123.6	123.3	121.6
Moisture	(%)	5.9	16.8	15.6
Void Ratio		0.262	0.190	0.177

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	24.3
Cohesion (c)	(kPa)	15.20



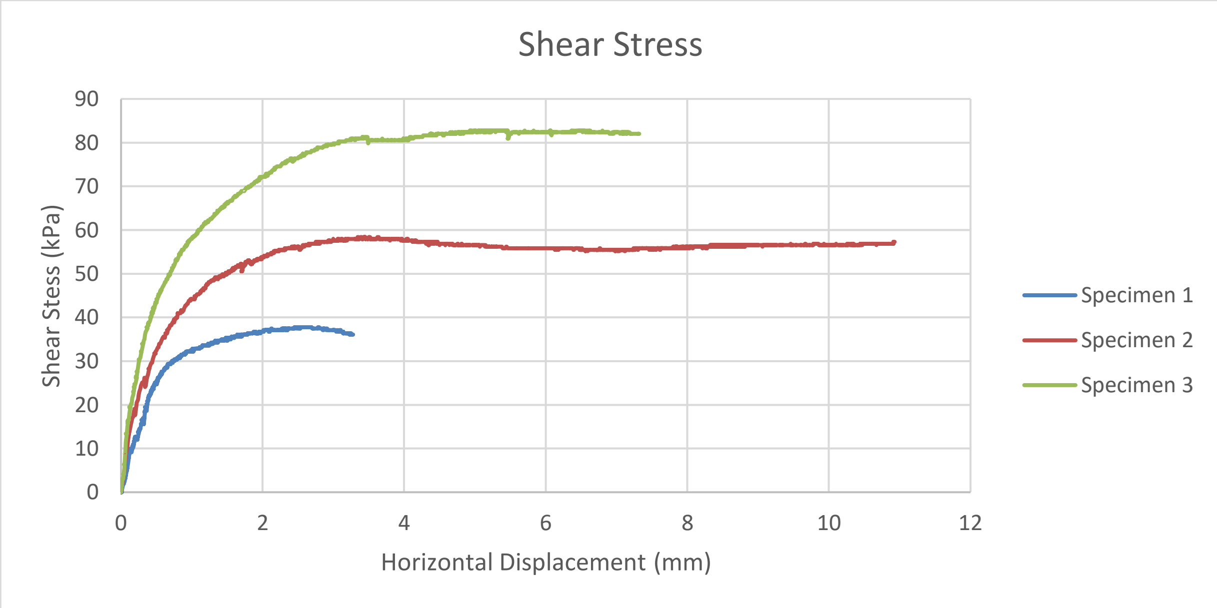


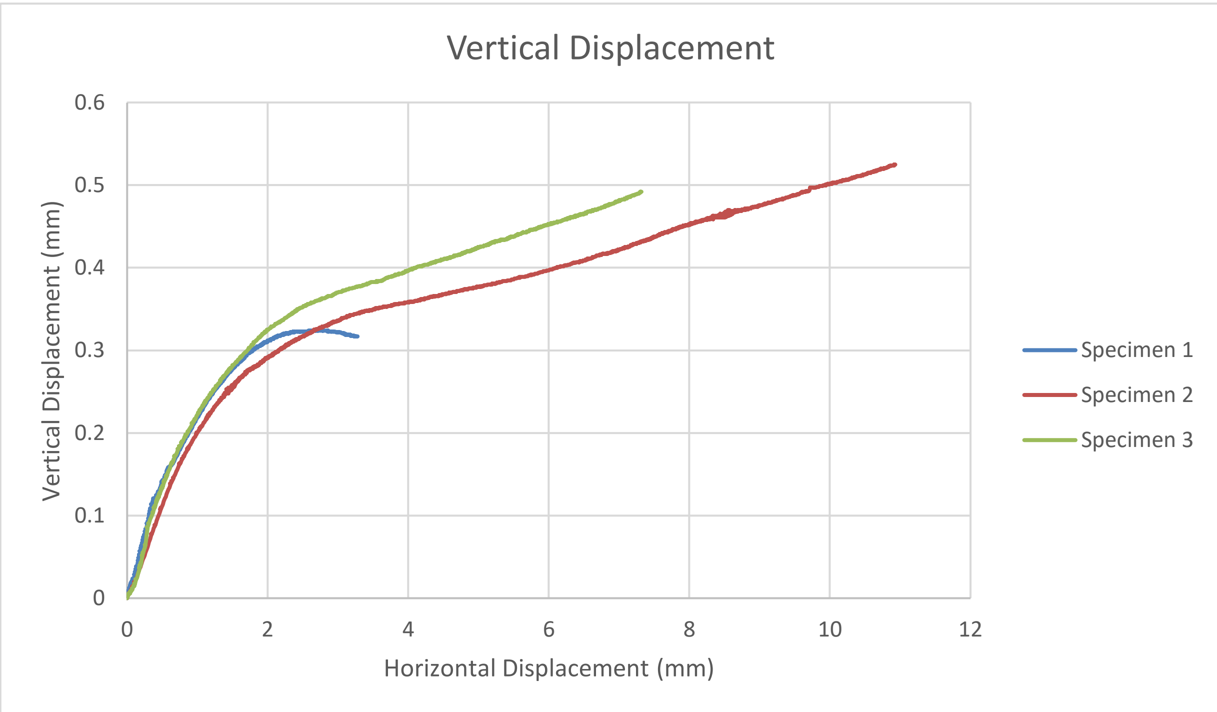
STEYN-WILSON GEOTECHNICAL	Test Method BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference	Test Date	03/08/2020
	Jobfile SWG00088	Sample	JD_TP10_0.0-0.7m
	Client Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC Checked: FC	Approved: FC	

Direct Shear Test

Graphs

Friction Angle (ϕ)	(°)	24.3
Cohesion (c)	(kPa)	15.20





STEYN-WILSON GEOTECHNICAL	Test Method	BS1377 - 7: 1990	Test Name Database: .\SQLEXPRESS \ Steyn Wilson Geotech	
	Site Reference		Test Date	03/08/2020
	Jobfile	SWG00088	Sample	JD_TP10_0.0-0.7m
	Client	Zutari	Borehole	Clanwilliam Bridging Study
	Operator:FC	Checked: FC	Approved: FC	

Labco Southern Africa (Pty) Ltd

sanas T0293

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Phone: +27 (0)21 905 0515 ■ +27 (0)21 905 0498
15 Warrior Crescent, Blackheath ■ PO Box 6627, Kraaifontein North, 7572

Client	:	Zutari (PTY) Ltd			
Address	:	P.O Box 494	**Client Reference**	:	
	:	Cape Town, South Africa	**Order No.**	:	
	:				
Attention	:	Keshia Myburgh	**Date Received**	:	07/08/2020
Facsimile	:	n/a	**Date Tested**	:	07/08/2020 - 01/09/2020
E-mail	:	Shavindh.Soorju@aurecongroup.com; Anton.:	**Date Reported**	:	01/09/2020
Project	:	Clanwilliam Bridging study			
Project No.	:	2020-C-966	**Report Status**	:	Final Report
			Page	:	1 of 31

Herewith please find the test report(s) pertaining to the above project. All tests were conducted in accordance with prescribed test method(s). Information herein consists of the following:

Test(s) conducted / Item(s) measured	Qty.	Test Method(s)	Authorized By**	Page(s)
pH of Soil	17.000	TMH1 A20	S de Vlam	2-18
Conductivity of saturated soil paste	17.000	TMH1 A21T	S de Vlam	2-18
Atterberg Limits <0.425mm	17.000	SANS 3001-GR10	S de Vlam	19-31
Sieve Analysis 0.075mm	17.000	SANS 3001-GR1	S de Vlam	19-31
California Bearing Ratio (CBR)	8.000	SANS 3001-GR40	S de Vlam	28-31
Hydrometer Analysis*	17.000	SANS 3001-GR3	S de Vlam	19-27

Any test results contained in this report and marked with * in the table above are "not SANAS accredited" and are not included in the schedule of accreditation for this laboratory.

Any information contained in this test report pertain only to the areas and/or samples tested. Documents may only be reproduced or published in their full context. • Any information gained by the laboratory prior, during or after test process will be treated as confidential and will not be reproduced or disclosed to any person or organization, unless required by law.
All interpretations, Interpolations, Opinions and/or Classifications contained in this report falls outside our scope of accreditation.

The following parameters, where applicable, were excluded from the classification procedure: Chemical modifications, Additional fines, Fractured Faces, Soluble Salts, pH, Conductivity, Coarse Sand Ratio, Durability (COLTO: G4-G9).

The following parameters, where applicable, were assumed: Rock types were assumed to be of an Arenaceous nature with Siliceous cementing material.

Unless otherwise requested or stated, all samples will be discarded after a period of 3 months.

Deviations in Test Methods:

**All results are authorized by technical signatories.

Technical Signatory.

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Client	:	Zutari (PTY) Ltd	Date Received:	07/08/2020
Project	:	Clanwilliam Bridging study	Date Reported:	01/09/2020
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AGGREGATE TEST REPORT

Laboratory Number		16
Field Number		JD TP21
Client Reference		
Depth (m)		0.0-1.3
Position		Jan Dissel Scheme
Coordinates	X	
	Y	
Description		Colluvium
Additional Information		
Calcrete/Crushed		
Stabilizing Agent		

% Passing			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
Sand Equivalent, Se				
pH		TMH1 A20	mS/m	3.97
Relative Density of Soils				
Durability Mill Index				
Moisture Content			%	
Compactibility Factor				
Conductivity		TMH1 A21T	mS/m	0.0105
Total Water Soluble	Salts		%	
	Sulphates			
Soluble	Salts		%	
	Sulphates			
Soundness	Fine		%	
	Coarse			
	Fractions		No.	
Methylene Blue Absorption				
Soluble Deleterious Impurities			%	
Chloride Content			%	
Low Density Material			%	
Presence of Sugar				
Mill Abrasion				
Treton Value				
Vialit Adhesion @	5°C		%	
	25°C		%	

Finess Modulus				
Clay Content		SANS 3001-GR3	%	3
Organic Impurities			Ref.	
Flakiness Index	Total		%	
Average Least Dimension	Manual		mm	
	Machine			
	Computation			
Aggregate Crushing Value	Dry		%	
	Wet			
	Eth. Glycol			
10% Fines Aggregate Crushing Test (FACT)	Dry		kN	
	Wet			
	Eth. Glycol			
	Wet/Dry Ratio		%	
Bulk Density	Loose		kg/m^3	
	Compacted			
Water Absorption			%	
Bulk Particle Density			kg/m^3	
	Aggregate			
Apparent Particle Density			kg/m^3	
	Adjusted			
	Relative			
LA Abrasion	1000 Revs		%	
	500 Revs			
Riedel & Weber				
Akali Silica Reaction			%	
Drying Shrinkage			%	
Wetting Expansion			%	
Fractured Faces			%	
Coarse Sand Ratio			%	
Shape: Voids			%	
Shell Content			%	
Durability Eth. Glycol Durability on _ Stone	Ballast			
	Concrete			
	Crushed			
	Seal			

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Client	:	Zutari (PTY) Ltd	Date Received:	07/08/2020
Project	:	Clanwilliam Bridging study	Date Reported:	01/09/2020
Project No	:	2020-C-966	Page No. :	17 of 31

AGGREGATE TEST REPORT

Laboratory Number		17
Field Number		JD TP10
Client Reference		
Depth (m)		0.0-0.7
Position		Jan Dissel Scheme
Coordinates	X	
	Y	
Description		Residual Sandstone
Additional Information		
Calcrete/Crushed		
Stabilizing Agent		

% Passing			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
Sand Equivalent, Se				
pH		TMH1 A20	mS/m	6.45
Relative Density of Soils				
Durability Mill Index				
Moisture Content			%	
Compactibility Factor				
Conductivity		TMH1 A21T	mS/m	0.138
Total Water Soluble	Salts		%	
	Sulphates			
Soluble	Salts		%	
	Sulphates			
Soundness	Fine		%	
	Coarse			
	Fractions		No.	
Methylene Blue Absorption				
Soluble Deleterious Impurities			%	
Chloride Content			%	
Low Density Material			%	
Presence of Sugar				
Mill Abrasion				
Treton Value				
Vialit Adhesion @	5°C		%	
	25°C		%	

Finess Modulus				
Clay Content		SANS 3001-GR3	%	17
Organic Impurities			Ref.	
Flakiness Index	Total		%	
Average Least Dimension	Manual		mm	
	Machine			
	Computation			
Aggregate Crushing Value	Dry		%	
	Wet			
	Eth. Glycol			
10% Fines Aggregate Crushing Test (FACT)	Dry		kN	
	Wet			
	Eth. Glycol			
	Wet/Dry Ratio		%	
Bulk Density	Loose		kg/m^3	
	Compacted			
Water Absorption			%	
Bulk Particle Density			kg/m^3	
	Aggregate			
Apparent Particle Density			kg/m^3	
	Adjusted			
	Relative			
LA Abrasion	1000 Revs		%	
	500 Revs			
Riedel & Weber				
Akali Silica Reaction			%	
Drying Shrinkage			%	
Wetting Expansion			%	
Fractured Faces			%	
Coarse Sand Ratio			%	
Shape: Voids			%	
Shell Content			%	
Durability Eth. Glycol Durability on _ Stone	Ballast			
	Concrete			
	Crushed			
	Seal			

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Client	:	Zutari (PTY) Ltd	Date Received:	07/08/2020
Project	:	Clanwilliam Bridging study	Date Reported:	01/09/2020
Project No	:	2020-C-966	Page No. :	18 of 31

AGGREGATE TEST REPORT

Laboratory Number		18
Field Number		JD TP15
Client Reference		
Depth (m)		0.0-1.20
Position		Jan Dissel Scheme
Coordinates	X	
	Y	
Description		Colluvium & Residual Qtz Sandstone
Additional Information		
Calcrete/Crushed		
Stabilizing Agent		

% Passing			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
			mm	
Sand Equivalent, Se				
pH		TMH1 A20	mS/m	4.46
Relative Density of Soils				
Durability Mill Index				
Moisture Content			%	
Compactibility Factor				
Conductivity		TMH1 A21T	mS/m	0.0106
Total Water Soluble	Salts		%	
	Sulphates			
Soluble	Salts		%	
	Sulphates			
Soundness	Fine		%	
	Coarse			
	Fractions		No.	
Methylene Blue Absorption				
Soluble Deleterious Impurities			%	
Chloride Content			%	
Low Density Material			%	
Presence of Sugar				
Mill Abrasion				
Treton Value				
Vialit Adhesion @	5°C		%	
	25°C		%	

Finess Modulus				
Clay Content		SANS 3001-GR3	%	2
Organic Impurities			Ref.	
Flakiness Index	Total		%	
Average Least Dimension	Manual		mm	
	Machine			
	Computation			
Aggregate Crushing Value	Dry		%	
	Wet			
	Eth. Glycol			
10% Fines Aggregate Crushing Test (FACT)	Dry		kN	
	Wet			
	Eth. Glycol			
	Wet/Dry Ratio		%	
Bulk Density	Loose		kg/m^3	
	Compacted			
Water Absorption			%	
Bulk Particle Density			kg/m^3	
	Aggregate			
Apparent Particle Density			kg/m^3	
	Adjusted			
	Relative			
LA Abrasion	1000 Revs		%	
	500 Revs			
Riedel & Weber				
Akali Silica Reaction			%	
Drying Shrinkage			%	
Wetting Expansion			%	
Fractured Faces			%	
Coarse Sand Ratio			%	
Shape: Voids			%	
Shell Content			%	
Durability	Ballast			
Eth. Glycol	Concrete			
Durability on	Crushed			
_ Stone	Seal			

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Client	: Zutari (PTY) Ltd	Date Received:		07/08/2020
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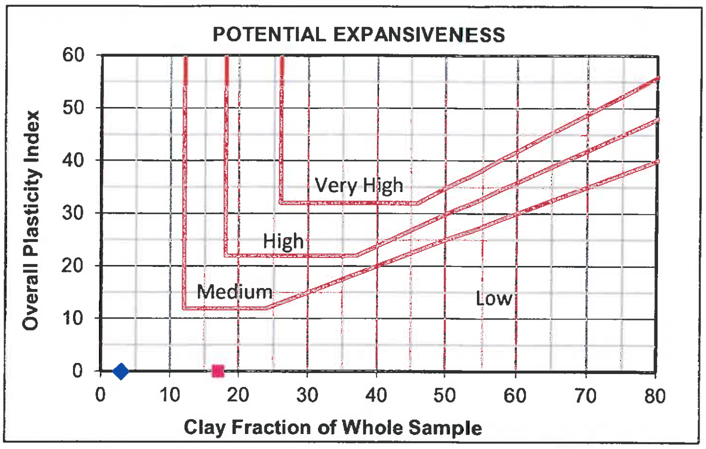
FOUNDATION INDICATOR

Laboratory Number		16 ◆	17 ■
Field Number		JD TP21	JD TP10
Client Reference			
Depth (m)		0.0-1.3	0.0-0.7
Position		Jan Dissel Scheme	Jan Dissel Scheme
Coordinates	X		
	Y		
Description		Colluvium	Residual Sandstone
Aditional Information			
Calcrete / Crushed Stabilizing Agent			

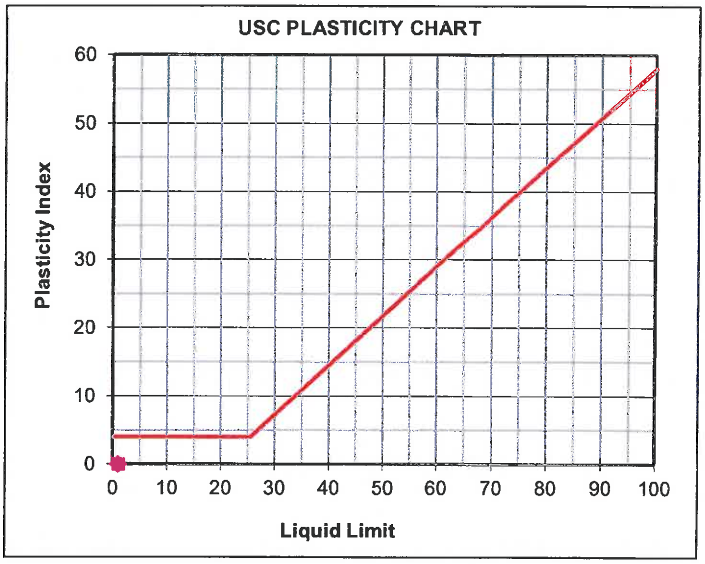


Moisture Content & Relative Density

Moisture Content (%)		
Relative Density (S.G.)		

Sieve Analysis (Wet Prep) SANS 3001-GR1

		16	17
Percentage Passing	100 mm	100	100
	75 mm	100	100
	63 mm	100	100
	50 mm	100	100
	37.5 mm	100	99
	28 mm	100	99
	20 mm	100	99
	14 mm	100	99
	5 mm	98	98
	2 mm	95	98
	0.425 mm	49	83
	0.250 mm	33	58
	0.150 mm	22	38
	0.075 mm	13	29
Grading Modulus		1.43	0.90

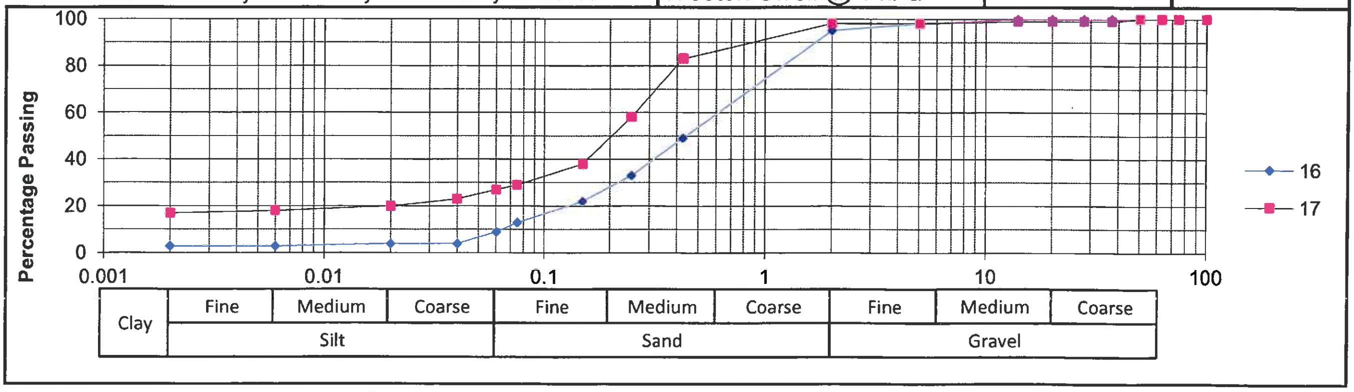


Hydrometer Analysis SANS 3001-GR3

		16	17
Percentage Passing	0.060 mm	9	27
	0.040 mm	4	23
	0.020 mm	4	20
	0.006 mm	3	18
	0.002 mm	3	17
Gravel	%	5	2
Sand	%	86	71
Silt	%	6	10
Clay	%	3	17

Note: An assumed S.G. may be used in Hydrometer Analysis calculations

Laboratory Number		16 ◆	17 ■
Atterberg Limits -425µ		**SANS 3001-GR10**	
Liquid Limit	%		
Plasticity Index	%	NP	NP
Linear Shrinkage	%		1.0
Overall PI	%		
Classifications			
HRB (AASHTO)		A-1-b(0)	A-2-4(0)
Unified (ASTM D2487)		SM	SM
Weston Swell @ 1 kPa			



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Project :	Clanwilliam Bridging study	Date Reported:	01/09/2020
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FOUNDATION INDICATOR

Laboratory Number		18 ◆	■
Field Number		JD TP15	
Client Reference			
Depth (m)		0.0-1.20	
Position		Jan Dissel Scheme	
Coordinates	X		
	Y		
Description		Colluvium & Residual Qtz Sandstone	
Aditional Information			
Calcrete / Crushed			
Stabilizing Agent			

Moisture Content & Relative Density — **SANS 3001-GR30**

Moisture Content (%)		
Relative Density (S.G.)		

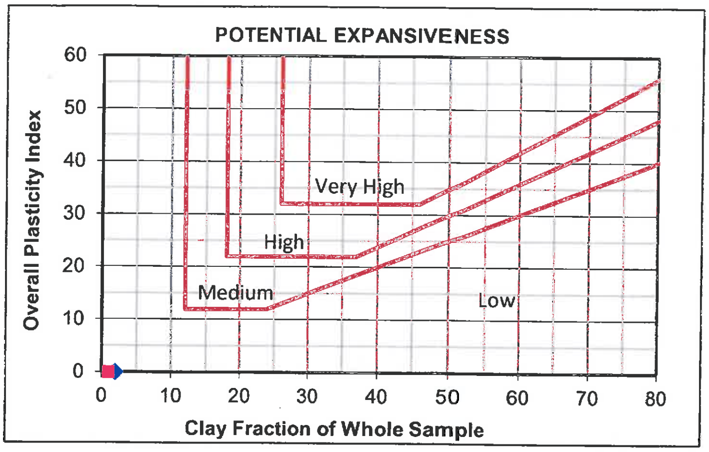
Sieve Analysis (Wet Prep) — **SANS 3001-GR1**

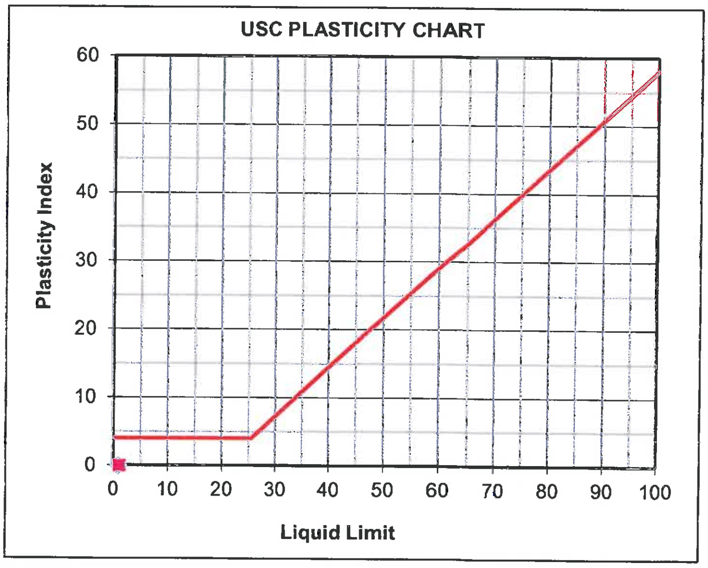
Percentage Passing	100 mm	100	
	75 mm	100	
	63 mm	100	
	50 mm	100	
	37.5 mm	100	
	28 mm	100	
	20 mm	100	
	14 mm	98	
	5 mm	94	
	2 mm	80	
	0.425 mm	42	
	0.250 mm	22	
	0.150 mm	12	
	0.075 mm	4	
Grading Modulus		1.74	

Hydrometer Analysis — **SANS 3001-GR3**

Percentage Passing	0.060 mm	4	
	0.040 mm	4	
	0.020 mm	3	
	0.006 mm	3	
	0.002 mm	2	
Gravel	%	20	
Sand	%	76	
Silt	%	2	
Clay	%	2	

Note: An assumed S.G. may be used in Hydrometer Analysis calculations





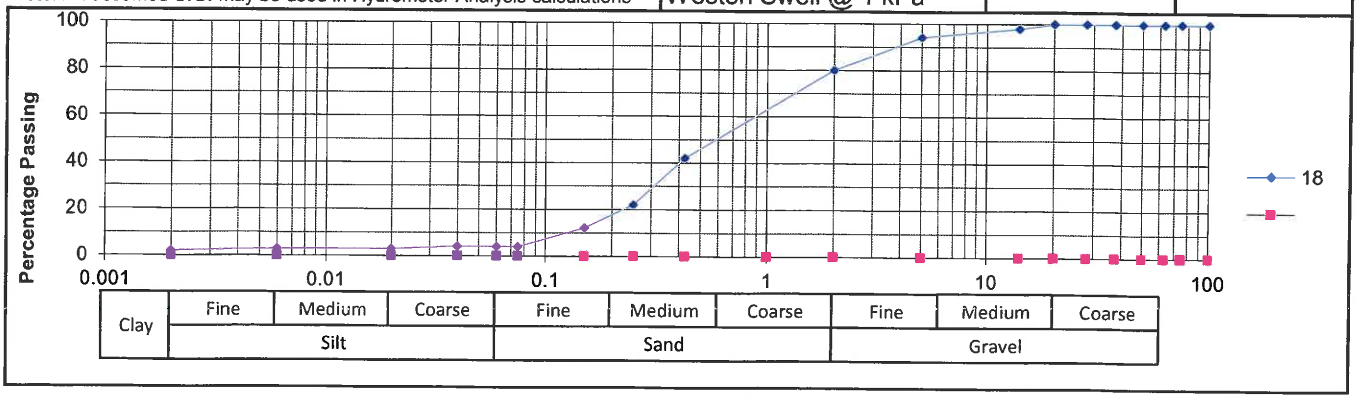
Laboratory Number		18 ◆	■

Atterberg Limits -425µ — **SANS 3001-GR10**

Liquid Limit	%		
Plasticity Index	%	NP	
Linear Shrinkage	%		
Overall PI	%		

Classifications

HRB (AASHTO)	A-1-b(0)	
Unified (ASTM D2487)	SP	
Weston Swell @ 1 kPa		



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Project	:	Clanwilliam Bridging study	Date Reported	:	01/09/2020
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CALIFORNIA BEARING RATIO (CBR) & ROAD INDICATOR REPORT

Laboratory No.		17 ◆	18 ■
Field Number		JD TP10	JD TP15
Client Reference			
Depth (m)		0.0-0.7	0.0-1.20
Position		Jan Dissel Scheme	Jan Dissel Scheme
Coordinates	X		
	Y		
Description		Residual Sandstone	Colluvium & Residual Qtz Sandstone
Additional information			
Calcrete/Crushed			
Stabilizing Agent			

Sieve Analysis (Wet preparation) SANS 3001-GR1

Percentage Passing	17	18
100 mm	100	100
75 mm	100	100
63 mm	100	100
50 mm	100	100
37.5 mm	99	100
28 mm	99	100
20 mm	99	100
14 mm	99	98
5 mm	98	94
2 mm	98	80
0.425 mm	83	42
0.250 mm	58	22
0.150 mm	38	12
0.075 mm	29	4
Grading Modulus	0.9	1.7

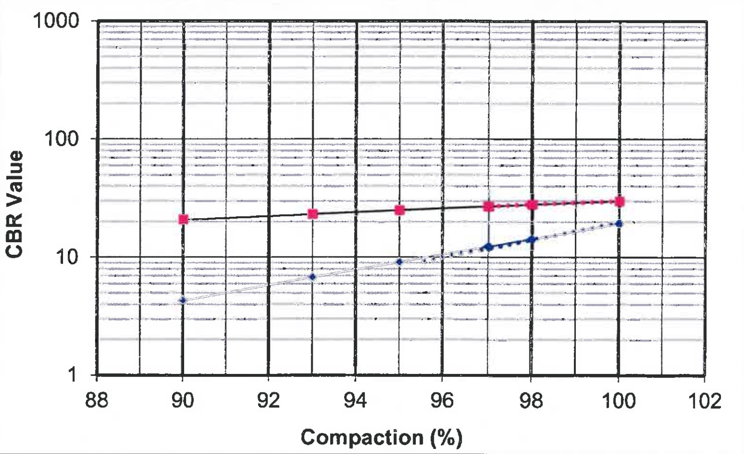
Soil Mortar Analysis

	17	18
Coarse Sand	15	48
Coarse Fine Sand	25	25
Medium Fine Sand	20	13
Fine Fine Sand	9	9
Silt and Clay	30	5

Atterberg Limits SANS 3001-GR10

	17	18
Liquid Limit (%)		
Plasticity Index (%)	NP	NP
Linear Shrinkage (%)	1.0	

Laboratory No.		17 ◆			18 ■		
Maximum Dry Density & Optimum Moisture Content					**SANS 3001-GR30**		
MDD	kg/m^3	2008			1949		
OMC	%	9.4			10.1		
California Bearing Ratio					**SANS 3001-GR40**		
Compaction Data							
Moisture	%	9.3			10.1		
Dry Density	kg/m^3	2007	1914	1846	1956	1894	1806
Compaction	%	100.0	95.4	92.0	100.0	96.8	92.3
Penetration Data							
CBR at	2.50 mm	20	9	6	30	27	22
	5.00 mm	27	9	7	32	27	21
	7.50 mm	30	8	7	37	32	29
Swell	%	0.8	1.1	1.5	0	0	0
Final Moisture (%)		14.8	15.8	16.1	12.1	13.5	21.3

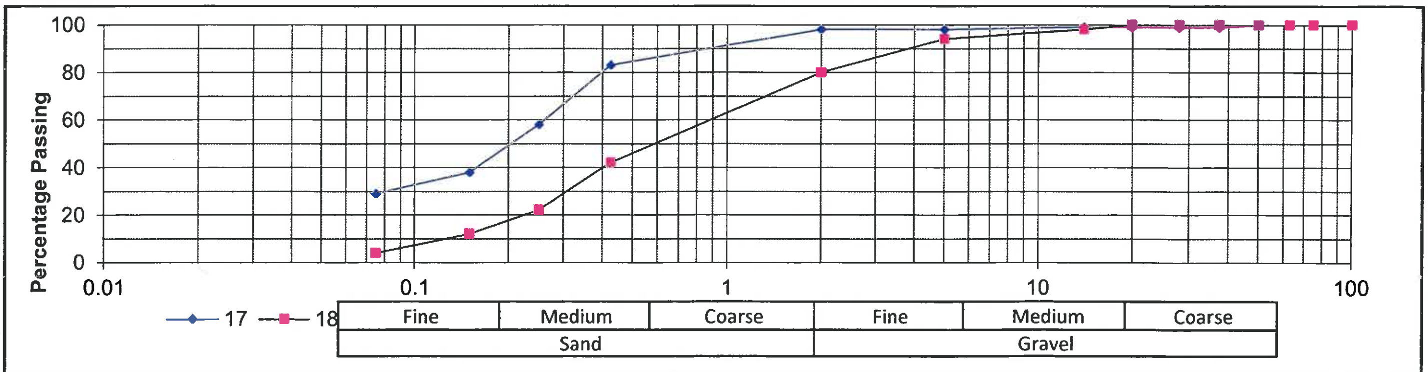


Interpolated CBR Data

CBR		Mod. AASHTO	17	18
@	100%		19	30
@	98%		14	28
@	97%		12	27
@	95%		9	25
@	93%		7	23
@	90%		4	21
@	SANS3001 Midpoint		14	28

Classifications

	17	18
HRB (AASHTO)	A-2-4(0)	A-1-b(0)
COLTO		G7
TRH14	G10	G7



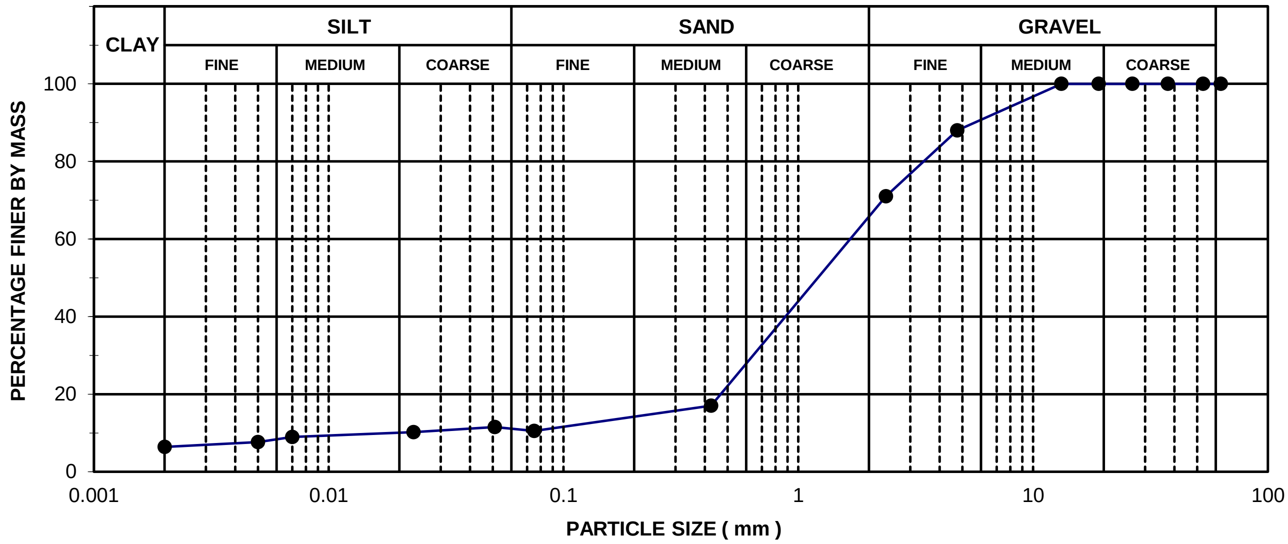
FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	JD TP22	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13602	PROJECT NUMBER	113834
DEPTH	0.6-1.2 m	SITE	Jan Dissel Scheme

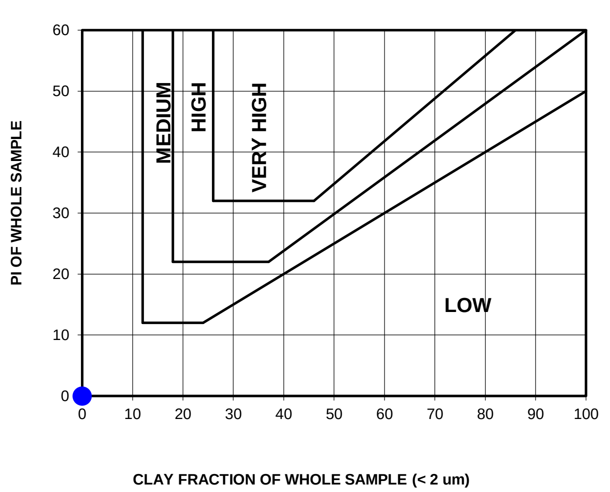
SIEVE ANALYSIS			
Sieve (mm)	% Passing	Sieve (mm)	% Passing
63.000	**100**	0.425	**17**
53.000	**100**	0.075	**11**
37.500	**100**	0.051	**12**
26.500	**100**	0.023	**10**
19.000	**100**	0.007	**9**
13.200	**100**	0.002	**6**
4.750	**88**	0.000	**0**
2.360	**71**	0.000	**0**

ATTERBERG LIMITS			SOIL CLASSIFICATION	
Liquid limit	(%)	**0.0**	% Gravel	**29**
Plastic limit	(%)	**0**	% Sand	**61**
Plasticity Index	(%)	**0**	% Silt	**4**
Weighted PI	(%)	**0**	% Clay	**6**
Linear Shrinkage	(%)	**0.0**	Activity	**0.0**
Grading Modulus		**2.02**	Unified Classification	**SP-SM**
Uniformity coefficient		**71**	TRB Classification	**A-- 1 - b**
Coefficient of curvature		**14.6**		

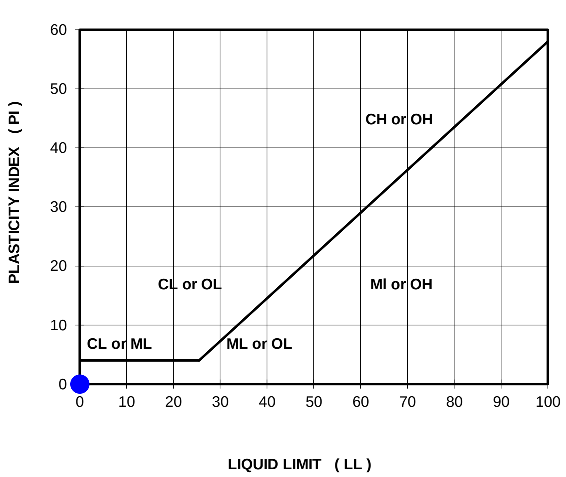
PARTICLE SIZE DISTRIBUTION



POTENTIAL EXPANSIVENESS
Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE

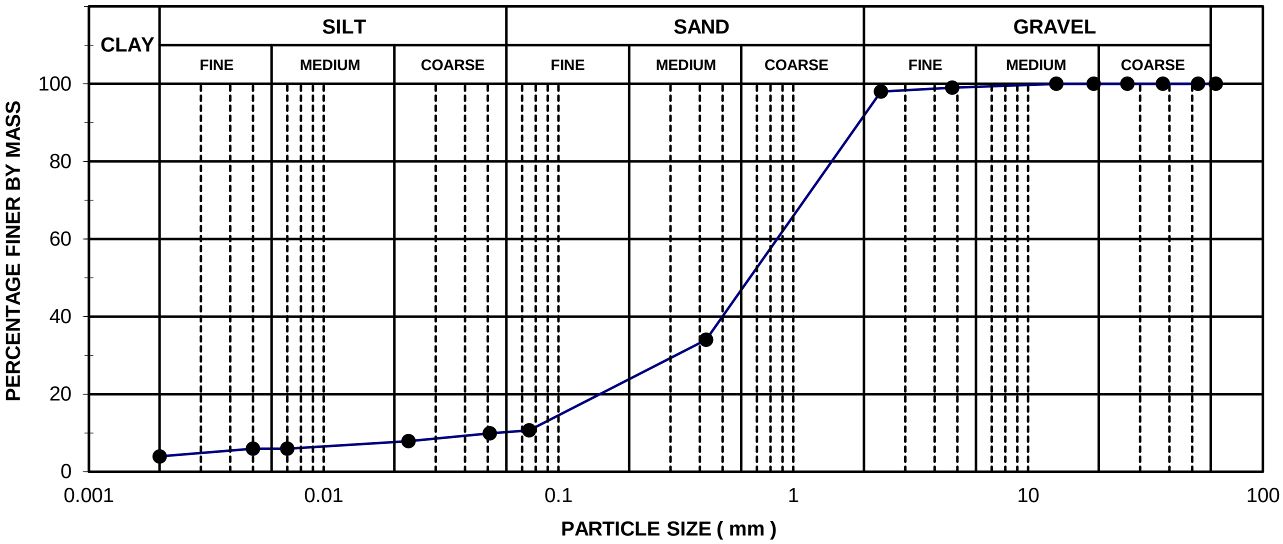


FOUNDATION INDICATOR TEST RESULTS

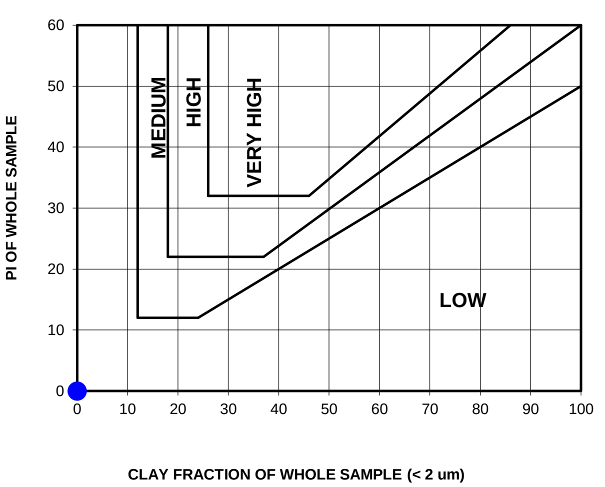
TEST LOCATION	JD TP04	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13592	PROJECT NUMBER	113834
DEPTH	0.0-0.4 m	SITE	Jan Dissel Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63.000	**100**	0.425	**34**	Liquid limit	(%)	**0.0**	% Gravel	**2**
53.000	**100**	0.075	**11**	Plastic limit	(%)	**0**	% Sand	**87**
37.500	**100**	0.051	**10**	Plasticity Index	(%)	**0**	% Silt	**7**
26.500	**100**	0.023	**8**	Weighted PI	(%)	**0**	% Clay	**4**
19.000	**100**	0.007	**6**	Linear Shrinkage	(%)	**0.0**	Activity	**0.0**
13.200	**100**	0.002	**4**	Grading Modulus		**1.57**	Unified Classification	**SW-SM**
4.750	**99**	0.000	**0**	Uniformity coefficient		**22**	TRB Classification	**A-- 1 - b**
2.360	**98**	0.000	**0**	Coefficient of curvature		**2.0**		

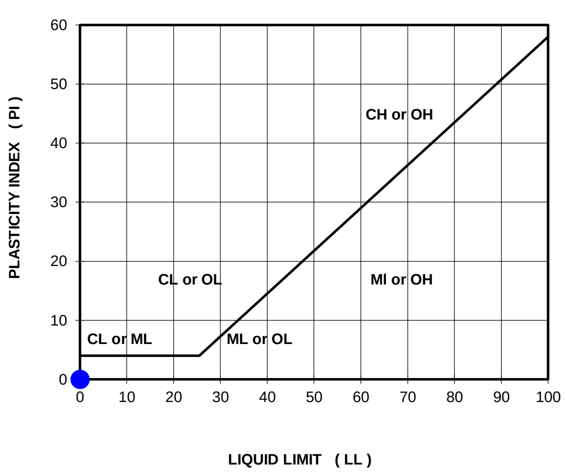
PARTICLE SIZE DISTRIBUTION



POTENTIAL EXPANSIVENESS
Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE

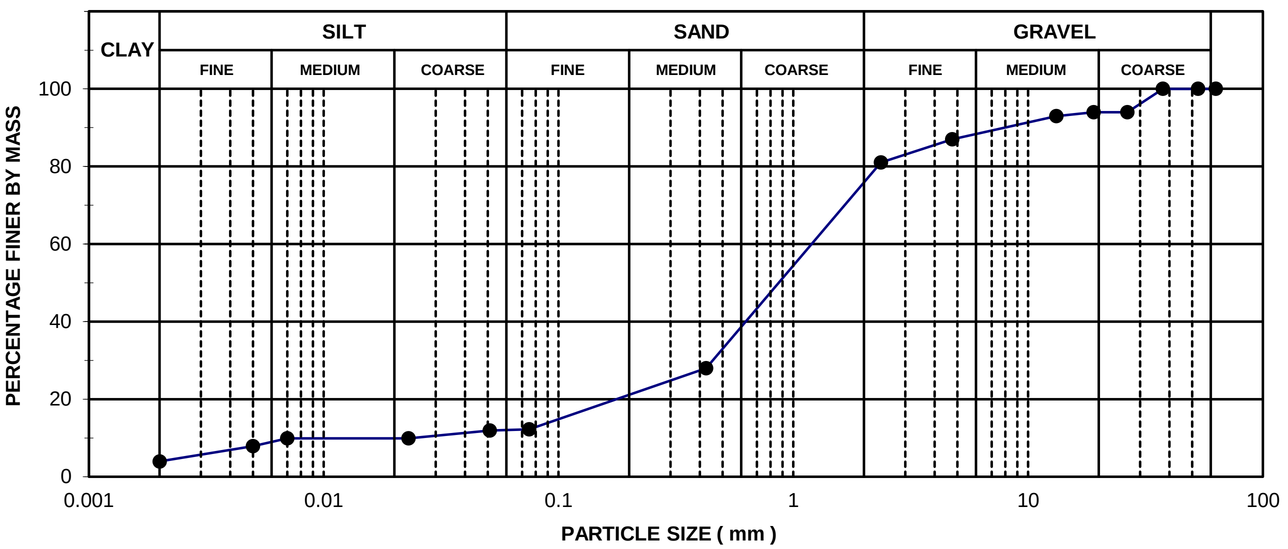


FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	JD TP05	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13593	PROJECT NUMBER	113834
DEPTH	0.2 - 0.7 m	SITE	Jan Dissel Scheme

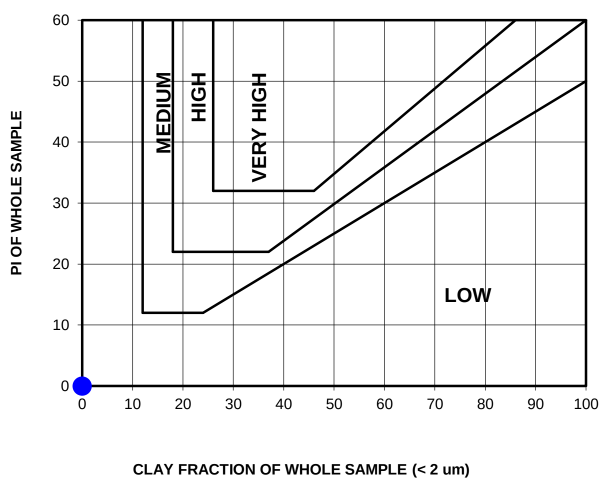
SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63.000	**100**	0.425	**28**	Liquid limit	(%)	**0.0**	% Gravel	**19**
53.000	**100**	0.075	**12**	Plastic limit	(%)	**0**	% Sand	**69**
37.500	**100**	0.051	**12**	Plasticity Index	(%)	**0**	% Silt	**8**
26.500	**94**	0.023	**10**	Weighted PI	(%)	**0**	% Clay	**4**
19.000	**94**	0.007	**10**	Linear Shrinkage	(%)	**0.0**	Activity	**0.0**
13.200	**93**	0.002	**4**	Grading Modulus		**1.79**	Unified Classification	**SM**
4.750	**87**	0.000	**0**	Uniformity coefficient		**50**	TRB Classification	**A-- 1 - b**
2.360	**81**	0.000	**0**	Coefficient of curvature		**4.9**		

PARTICLE SIZE DISTRIBUTION



POTENTIAL EXPANSIVENESS

Van der Merwe's Activity Chart



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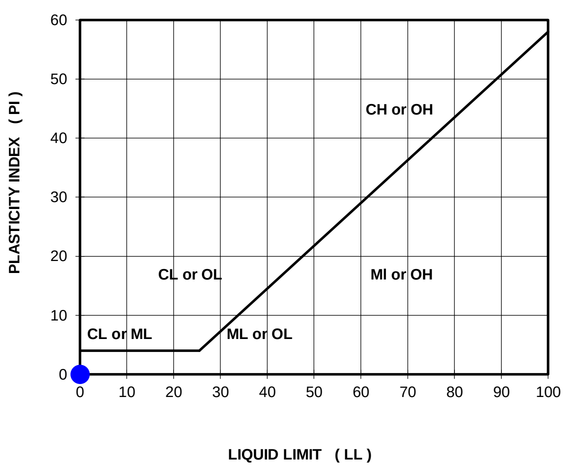


FOUNDATION INDICATOR TEST RESULTS

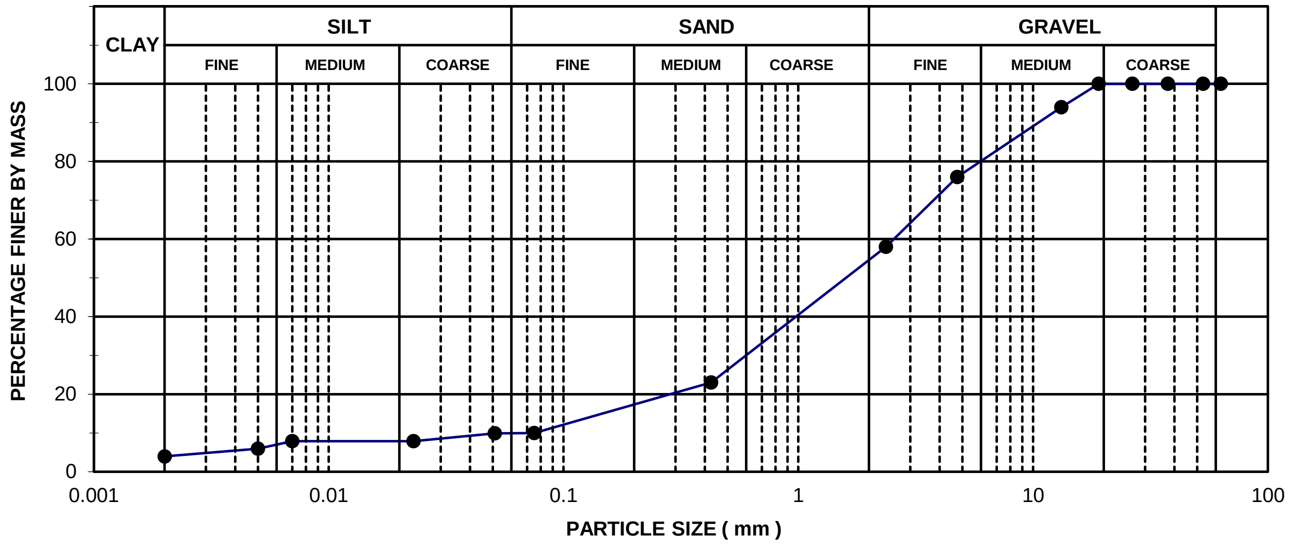
TEST LOCATION	JD TP06	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13594	PROJECT NUMBER	113834
DEPTH	0.15- 1.0 m	SITE	Jan Dissel Scheme

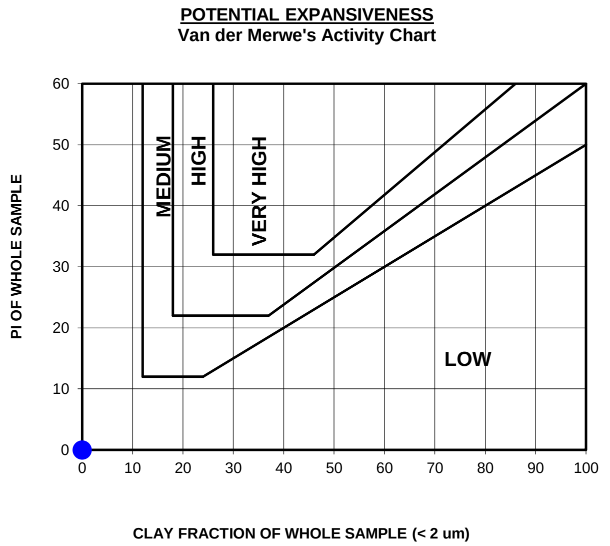
SIEVE ANALYSIS			
Sieve (mm)	% Passing	Sieve (mm)	% Passing
63.000	**100**	0.425	**23**
53.000	**100**	0.075	**10**
37.500	**100**	0.051	**10**
26.500	**100**	0.023	**8**
19.000	**100**	0.007	**8**
13.200	**94**	0.002	**4**
4.750	**76**	0.000	**0**
2.360	**58**	0.000	**0**

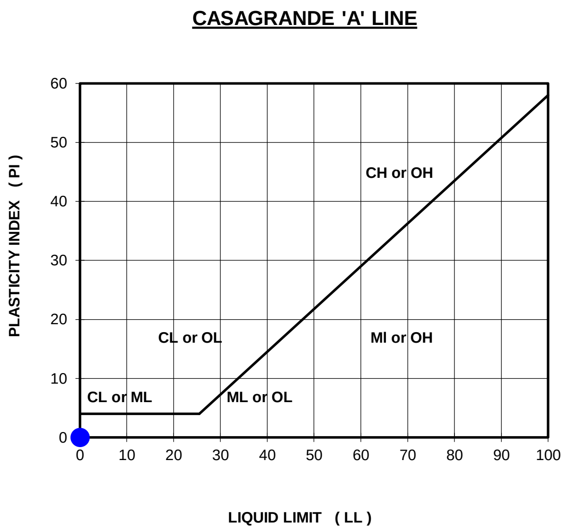
ATTERBERG LIMITS		
Liquid limit	(%)	**0.0**
Plastic limit	(%)	**0**
Plasticity Index	(%)	**0**
Weighted PI	(%)	**0**
Linear Shrinkage	(%)	**0.0**
Grading Modulus		**2.09**
Uniformity coefficient		**34**
Coefficient of curvature		**3.3**

SOIL CLASSIFICATION	
% Gravel	**42**
% Sand	**48**
% Silt	**6**
% Clay	**4**
Activity	**0.0**
Unified Classification	**SP-SM**
TRB Classification	**A-- 1 - b**

PARTICLE SIZE DISTRIBUTION





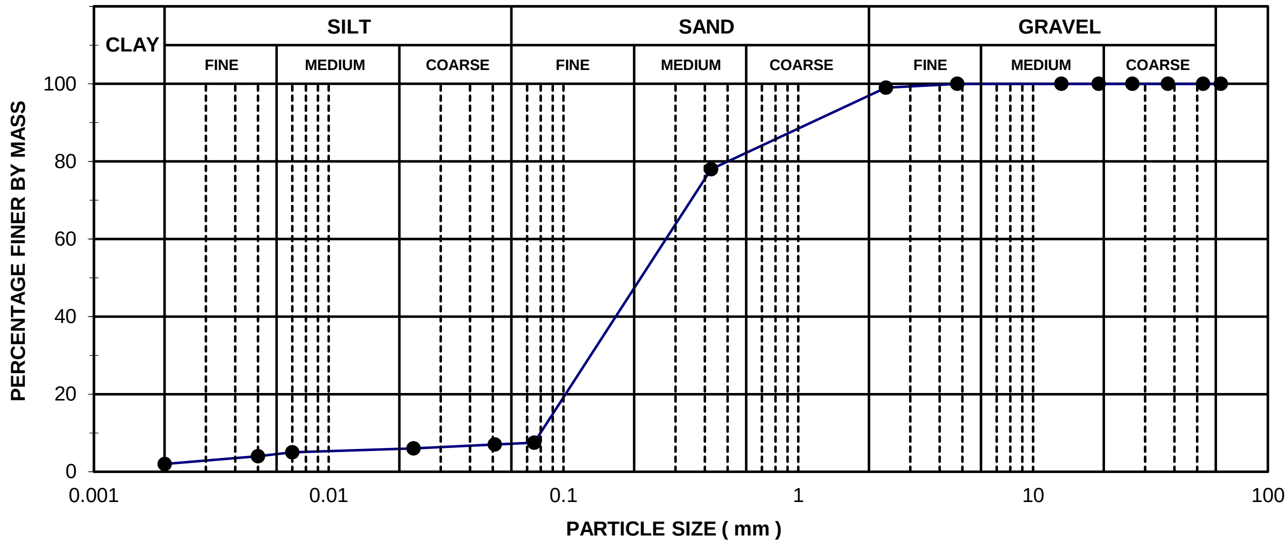


FOUNDATION INDICATOR TEST RESULTS

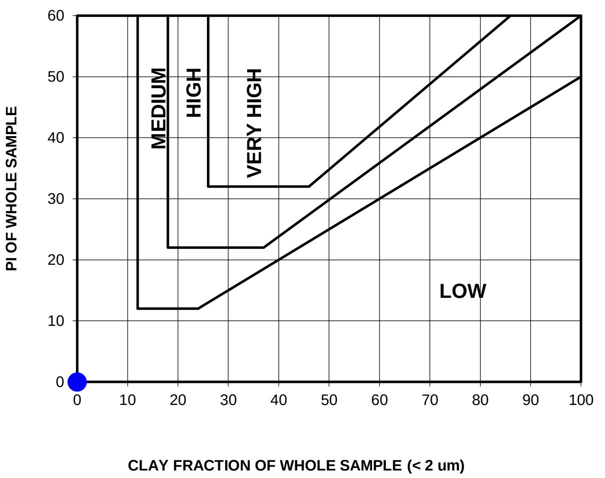
TEST LOCATION	JD TP09	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13595	PROJECT NUMBER	113834
DEPTH	0.0 - 1.1 m	SITE	Jan Dissel Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63.000	**100**	0.425	**78**	Liquid limit	(%)	**0.0**	% Gravel	**1**
53.000	**100**	0.075	**8**	Plastic limit	(%)	**0**	% Sand	**92**
37.500	**100**	0.051	**7**	Plasticity Index	(%)	**0**	% Silt	**6**
26.500	**100**	0.023	**6**	Weighted PI	(%)	**0**	% Clay	**2**
19.000	**100**	0.007	**5**	Linear Shrinkage	(%)	**0.0**	Activity	**0.0**
13.200	**100**	0.002	**2**	Grading Modulus		**1.16**	Unified Classification	**SP-SM**
4.750	**100**	0.000	**0**	Uniformity coefficient		**4**	TRB Classification	**A - 3**
2.360	**99**	0.000	**0**	Coefficient of curvature		**1.2**		

PARTICLE SIZE DISTRIBUTION



POTENTIAL EXPANSIVENESS
Van der Merwe's Activity Chart



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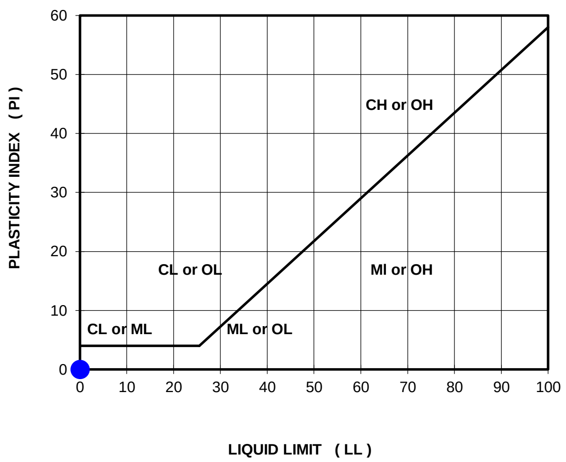
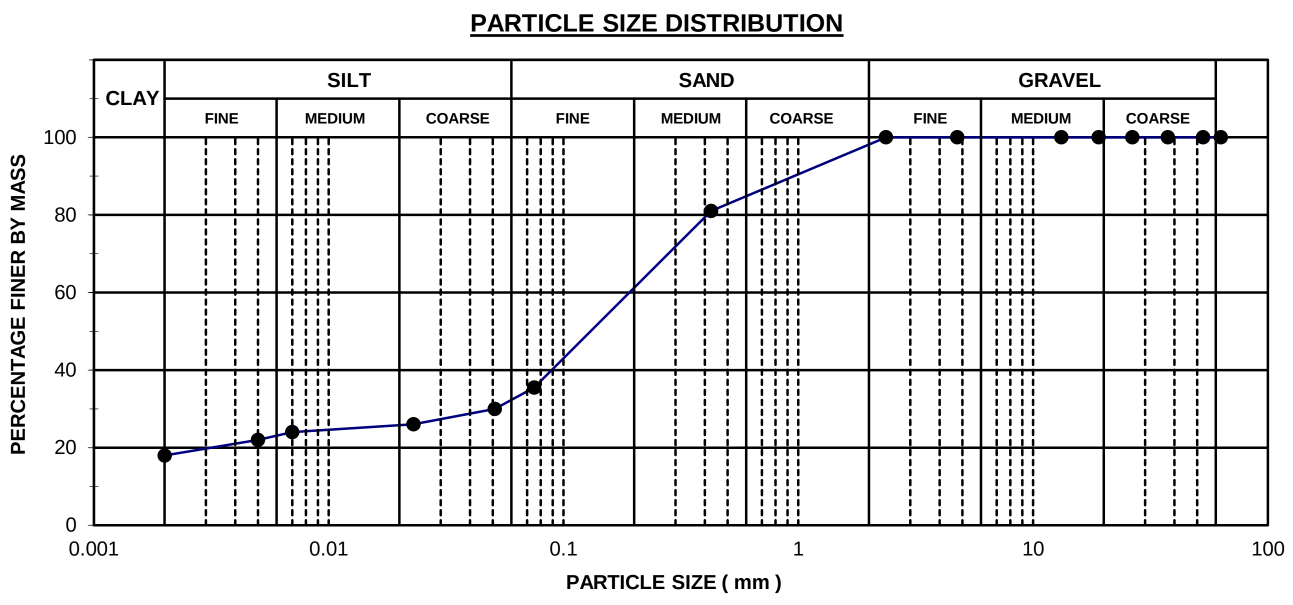
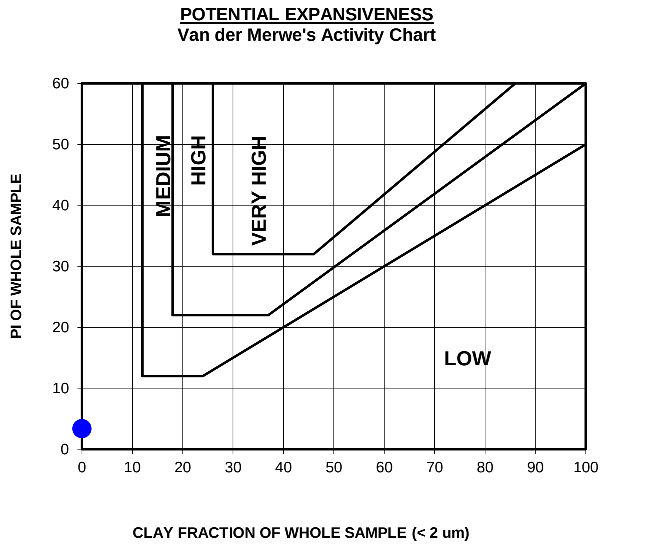


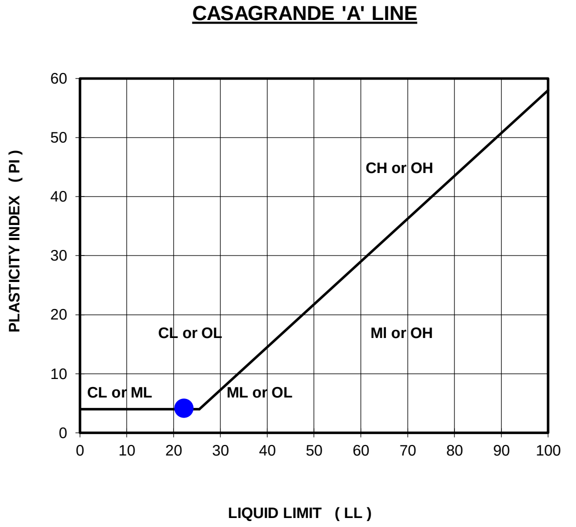
FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	JD TP10	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13596	PROJECT NUMBER	113834
DEPTH	0.0-0.7 m	SITE	Jan Dissel Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63.000	**100**	0.425	**81**	Liquid limit	(%)	**22.2**	% Gravel	**0**
53.000	**100**	0.075	**36**	Plastic limit	(%)	**18**	% Sand	**65**
37.500	**100**	0.051	**30**	Plasticity Index	(%)	**4**	% Silt	**18**
26.500	**100**	0.023	**26**	Weighted PI	(%)	**3**	% Clay	**18**
19.000	**100**	0.007	**24**	Linear Shrinkage	(%)	**1.9**	Activity	**0.2**
13.200	**100**	0.002	**18**	Grading Modulus		**0.84**	Unified Classification	**SC-SM**
4.750	**100**	0.000	**0**	Uniformity coefficient		**132**	TRB Classification	**A - 4**
2.360	**100**	0.000	**0**	Coefficient of curvature		**4.9**		







FOUNDATION INDICATOR TEST RESULTS

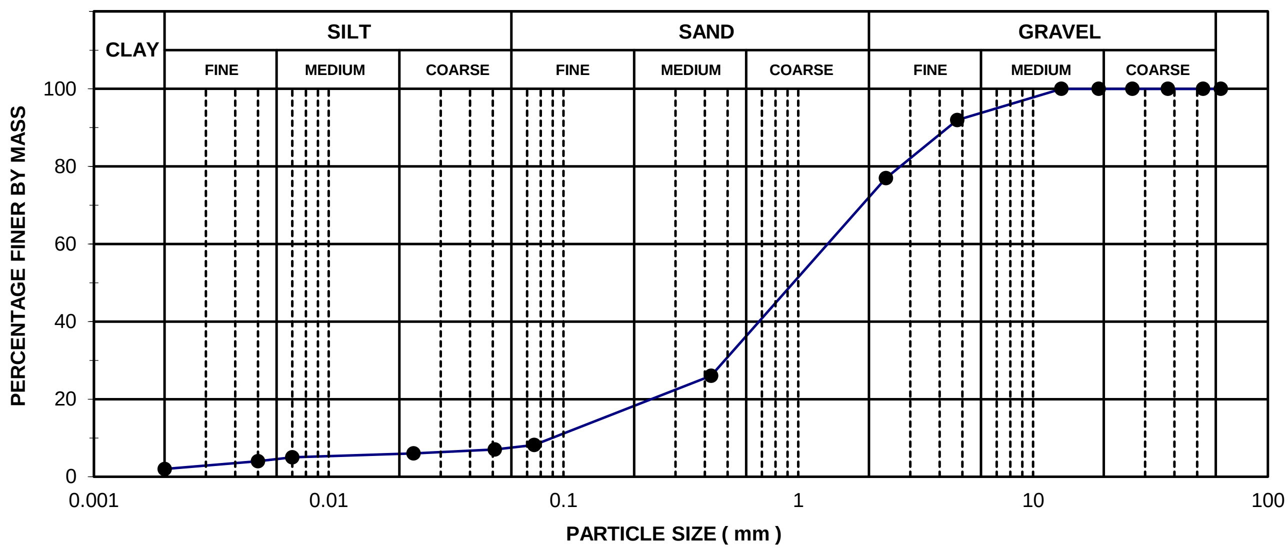
TEST LOCATION	JD TP11	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13597	PROJECT NUMBER	113834
DEPTH	0.1-0.9 m	SITE	Jan Dissel Scheme

SIEVE ANALYSIS			
Sieve (mm)	% Passing	Sieve (mm)	% Passing
63.000	**100**	0.425	**26**
53.000	**100**	0.075	**8**
37.500	**100**	0.051	**7**
26.500	**100**	0.023	**6**
19.000	**100**	0.007	**5**
13.200	**100**	0.002	**2**
4.750	**92**	0.000	**0**
2.360	**77**	0.000	**0**

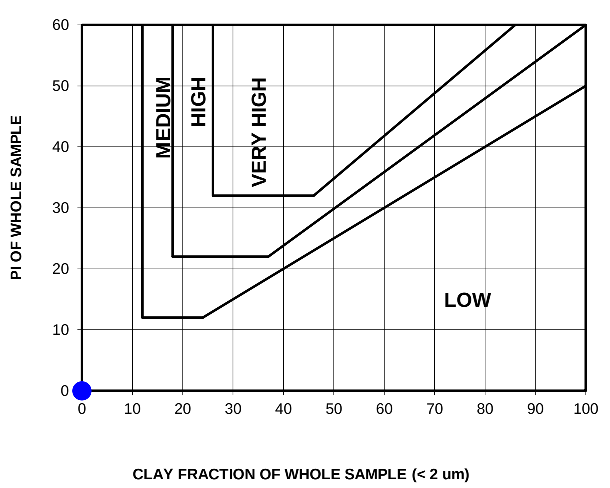
ATTERBERG LIMITS		
Liquid limit	(%)	**0.0**
Plastic limit	(%)	**0**
Plasticity Index	(%)	**0**
Weighted PI	(%)	**0**
Linear Shrinkage	(%)	**0.0**
Grading Modulus		**1.89**
Uniformity coefficient		**15**
Coefficient of curvature		**1.7**

SOIL CLASSIFICATION	
% Gravel	**23**
% Sand	**69**
% Silt	**6**
% Clay	**2**
Activity	**0.0**
Unified Classification	**SW-SM**
TRB Classification	**A-- 1 - b**

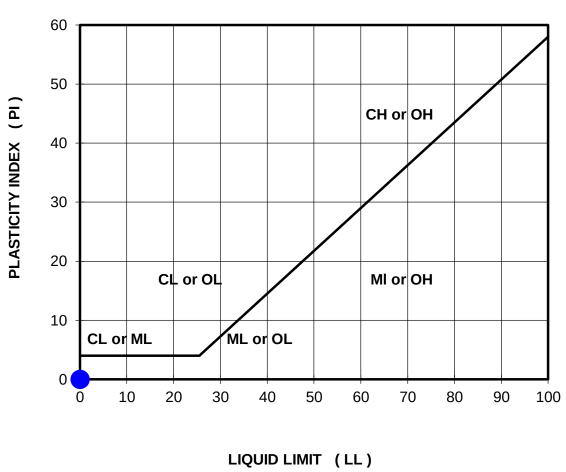
PARTICLE SIZE DISTRIBUTION



POTENTIAL EXPANSIVENESS
Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE

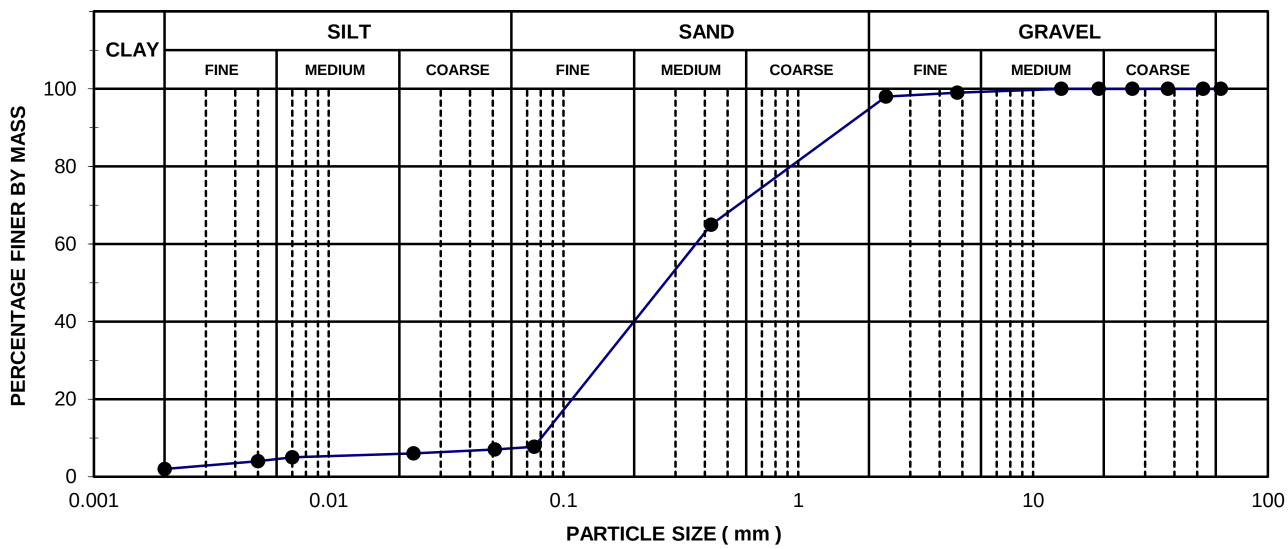


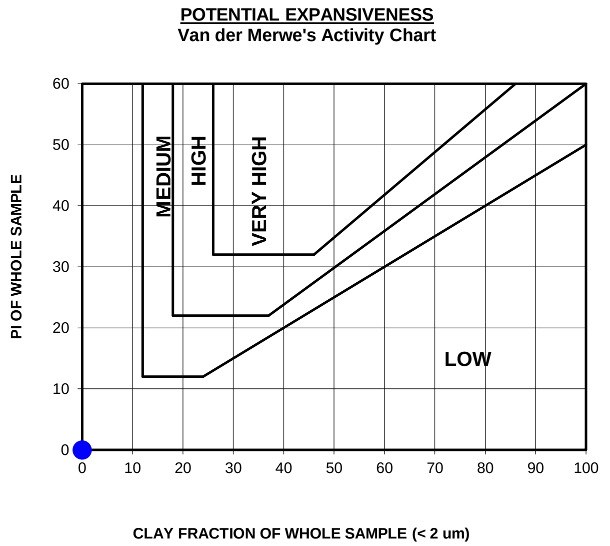
FOUNDATION INDICATOR TEST RESULTS

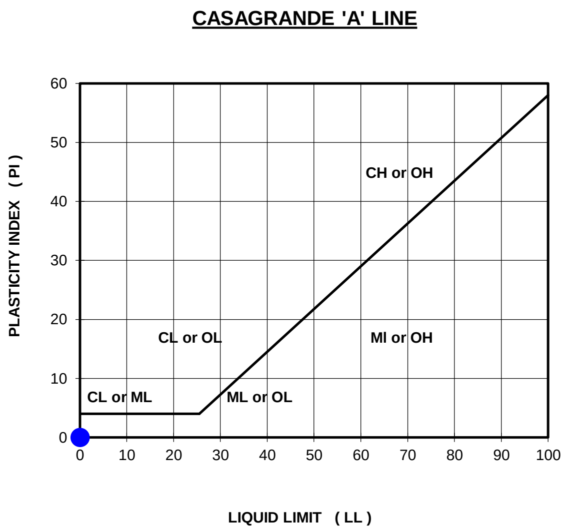
TEST LOCATION	JD TP12	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13598	PROJECT NUMBER	113834
DEPTH	0.0-0.5 m	SITE	Jan Dissel Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63.000	**100**	0.425	**65**	Liquid limit	(%)	**0.0**	% Gravel	**2**
53.000	**100**	0.075	**8**	Plastic limit	(%)	**0**	% Sand	**90**
37.500	**100**	0.051	**7**	Plasticity Index	(%)	**0**	% Silt	**6**
26.500	**100**	0.023	**6**	Weighted PI	(%)	**0**	% Clay	**2**
19.000	**100**	0.007	**5**	Linear Shrinkage	(%)	**0.0**	Activity	**0.0**
13.200	**100**	0.002	**2**	Grading Modulus		**1.29**	Unified Classification	**SP-SM**
4.750	**99**	0.000	**0**	Uniformity coefficient		**4**	TRB Classification	**A - 3**
2.360	**98**	0.000	**0**	Coefficient of curvature		**1.3**		

PARTICLE SIZE DISTRIBUTION





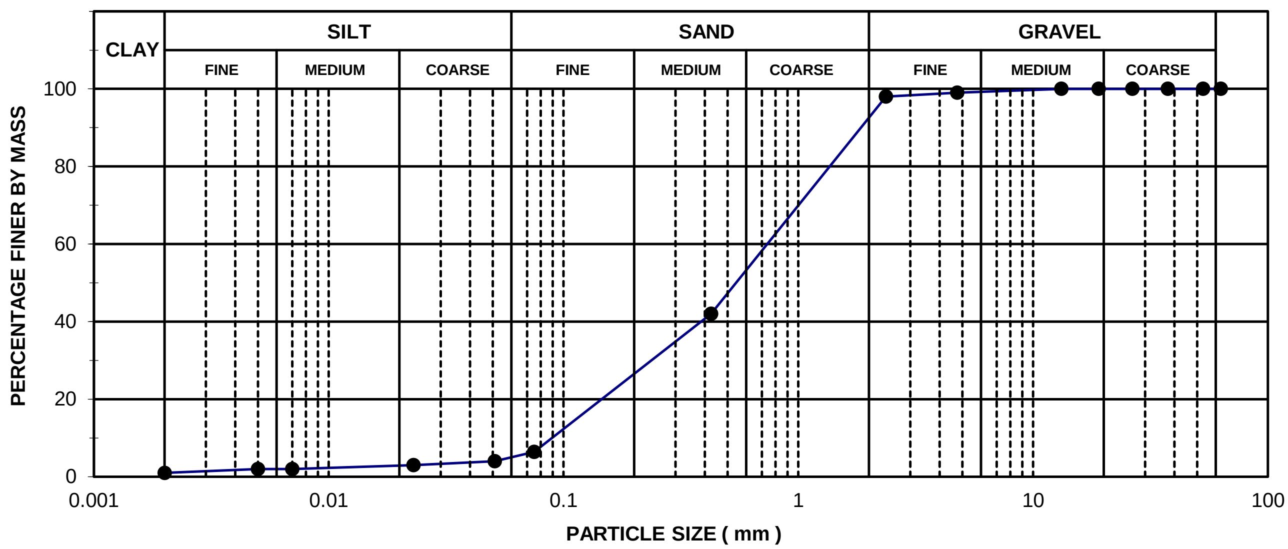


FOUNDATION INDICATOR TEST RESULTS

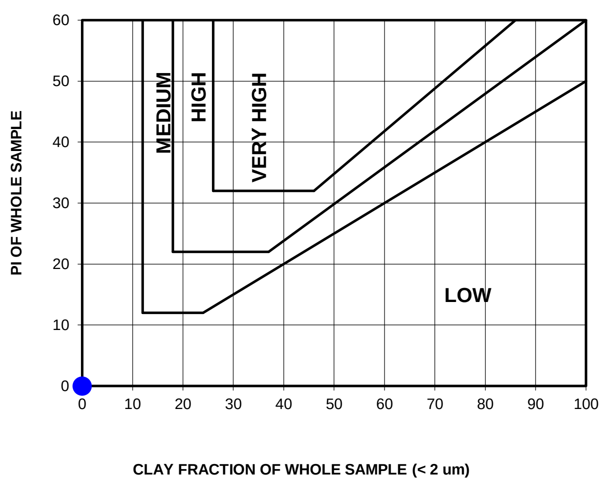
TEST LOCATION	JD TP14	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13599	PROJECT NUMBER	113834
DEPTH	0.0-1.6 m	SITE	Jan Dissel Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63.000	**100**	0.425	**42**	Liquid limit	(%)	**0.0**	% Gravel	**2**
53.000	**100**	0.075	**6**	Plastic limit	(%)	**0**	% Sand	**92**
37.500	**100**	0.051	**4**	Plasticity Index	(%)	**0**	% Silt	**5**
26.500	**100**	0.023	**3**	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		**1.54**	Unified Classification	**SP-SM**
4.750	**99**	0.000	**0**	Uniformity coefficient		**9**	TRB Classification	**A-- 1 - b**
2.360	**98**	0.000	**0**	Coefficient of curvature		**0.8**		

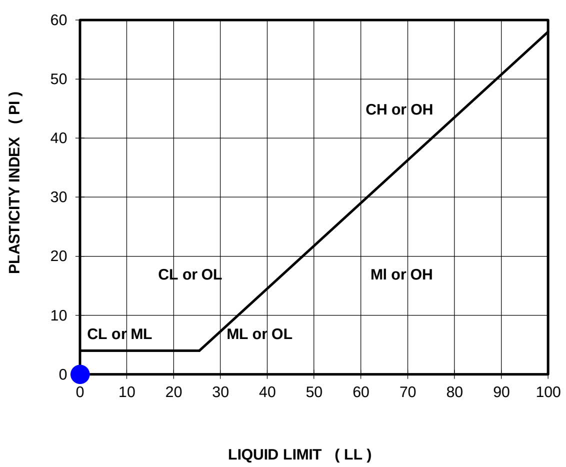
PARTICLE SIZE DISTRIBUTION



POTENTIAL EXPANSIVENESS
Van der Merwe's Activity Chart



CASAGRANDE 'A' LINE



FOUNDATION INDICATOR TEST RESULTS

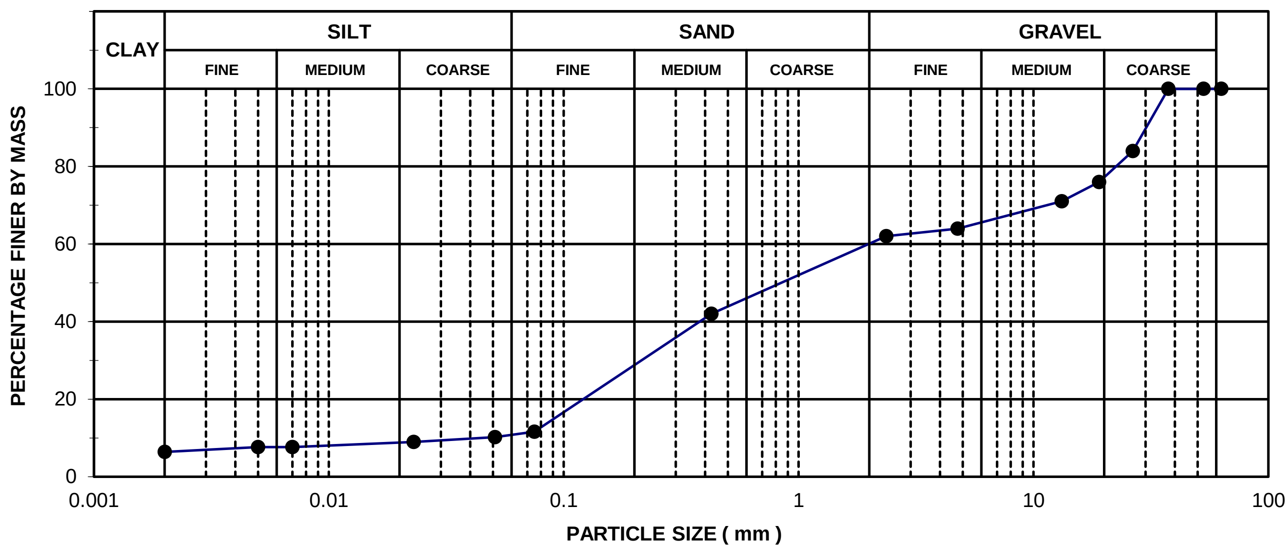
TEST LOCATION	JD TP16	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13600	PROJECT NUMBER	113834
DEPTH	0.0-1.4 m	SITE	Jan Dissel Scheme

SIEVE ANALYSIS			
Sieve (mm)	% Passing	Sieve (mm)	% Passing
63.000	**100**	0.425	**42**
53.000	**100**	0.075	**12**
37.500	**100**	0.051	**10**
26.500	**84**	0.023	**9**
19.000	**76**	0.007	**8**
13.200	**71**	0.002	**6**
4.750	**64**	0.000	**0**
2.360	**62**	0.000	**0**

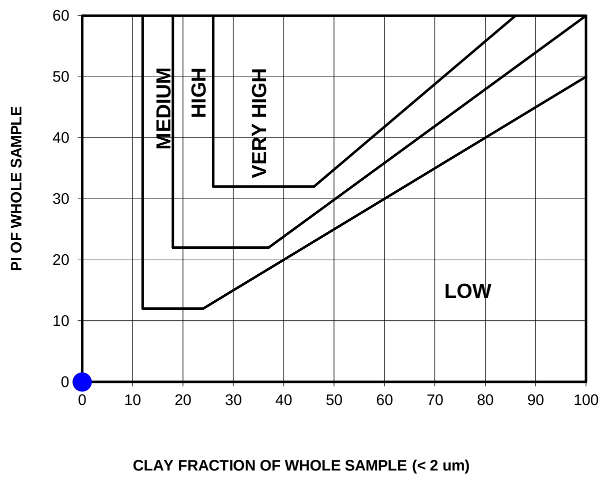
ATTERBERG LIMITS		
Liquid limit	(%)	**0.0**
Plastic limit	(%)	**0**
Plasticity Index	(%)	**0**
Weighted PI	(%)	**0**
Linear Shrinkage	(%)	**0.0**
Grading Modulus		**1.84**
Uniformity coefficient		**46**
Coefficient of curvature		**0.8**

SOIL CLASSIFICATION	
% Gravel	**38**
% Sand	**50**
% Silt	**5**
% Clay	**6**
Activity	**0.0**
Unified Classification	**SP-SM**
TRB Classification	**A-- 1 - b**

PARTICLE SIZE DISTRIBUTION



POTENTIAL EXPANSIVENESS
Van der Merwe's Activity Chart



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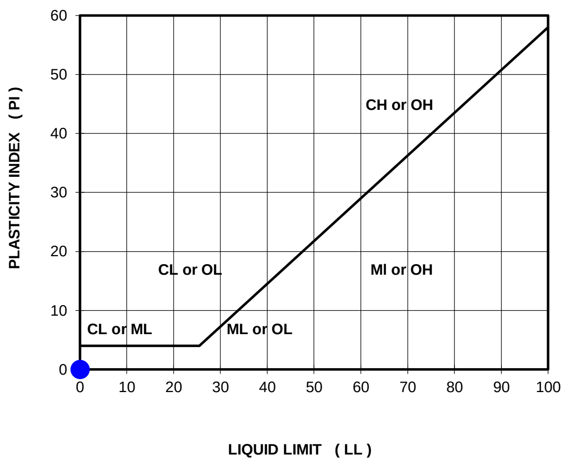
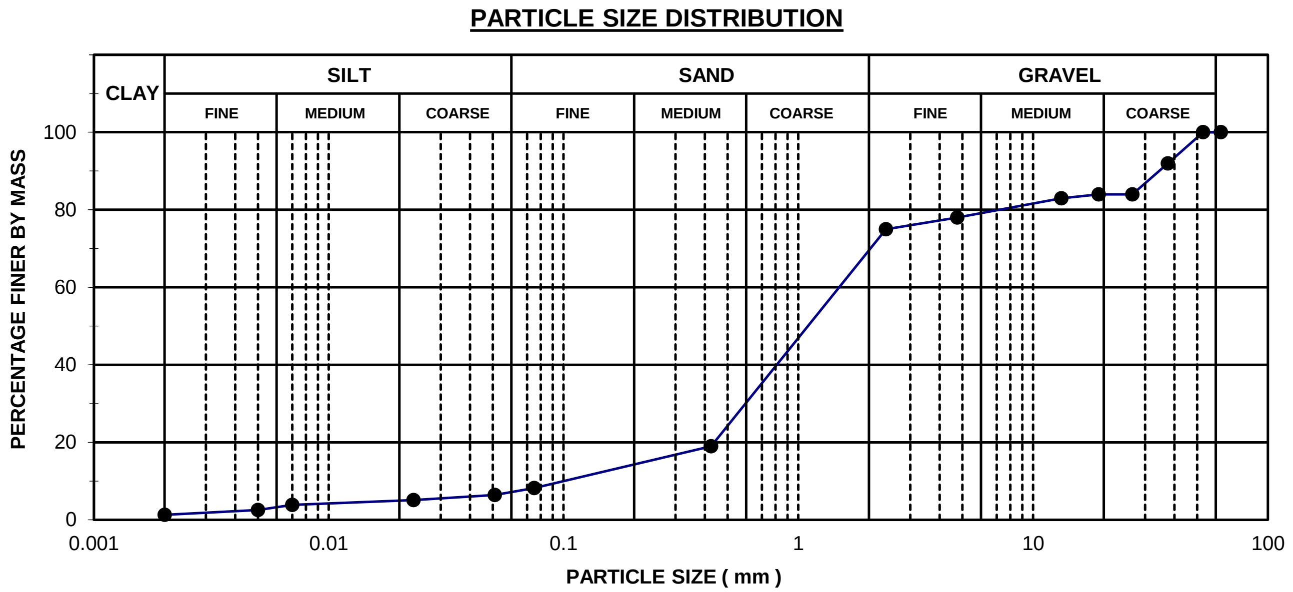
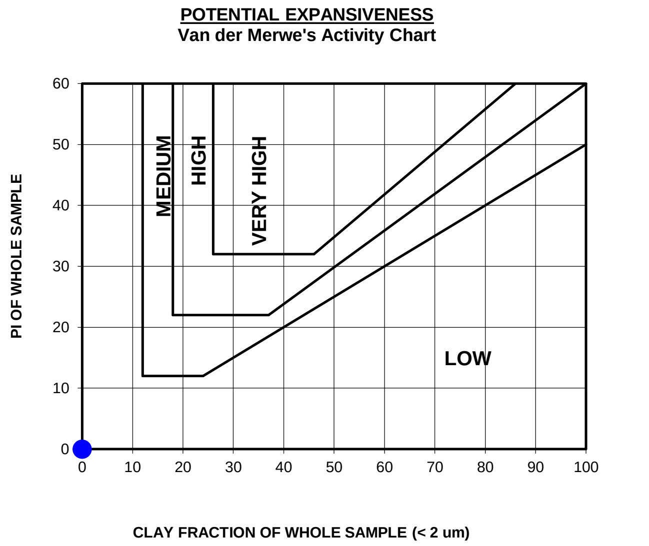


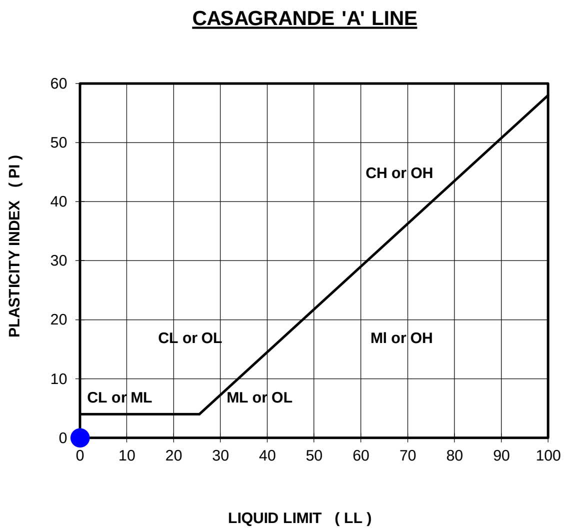
FOUNDATION INDICATOR TEST RESULTS

TEST LOCATION	JD TP21	PROJECT	Bridging Study Clanwilliam Dam
SAMPLE NO.	13601	PROJECT NUMBER	113834
DEPTH	0.0-0.3 m	SITE	Jan Dissel Scheme

SIEVE ANALYSIS				ATTERBERG LIMITS			SOIL CLASSIFICATION	
Sieve (mm)	% Passing	Sieve (mm)	% Passing					
63.000	**100**	0.425	**19**	Liquid limit	(%)	**0.0**	% Gravel	**25**
53.000	**100**	0.075	**8**	Plastic limit	(%)	**0**	% Sand	**67**
37.500	**92**	0.051	**6**	Plasticity Index	(%)	**0**	% Silt	**7**
26.500	**84**	0.023	**5**	Weighted PI	(%)	**0**	% Clay	**1**
19.000	**84**	0.007	**4**	Linear Shrinkage	(%)	**0.0**	Activity	**0.0**
13.200	**83**	0.002	**1**	Grading Modulus		**1.98**	Unified Classification	**SW-SM**
4.750	**78**	0.000	**0**	Uniformity coefficient		**14**	TRB Classification	**A-- 1 - b**
2.360	**75**	0.000	**0**	Coefficient of curvature		**2.6**		







Appendix F
Soil Resistivity Report and Detailed Results

Clanwilliam Dam Soil Electrical Resistivity Testing

Site Testing and Analysis Report

Department of Water and Sanitation

Aurecon Reference: 113834

Document Number: xxxxxxx

Revision: A

2020-08-12

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Bringing ideas to life

Document control record

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Project number		113834	**Document code**		xxxxxxx		
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Client		Department of Water and Sanitation					
Client contact		Mr M Mugumo	**Client reference**				
Rev	**Date**	**Revision details/status**	**Author**	**Reviewer**	**Verifier** (if required)	**Approver**	
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Current revision		**A**					

Approval			
Author signature		Approver signature	
Name	Paul McQueen	Name	Jannie Meuter
Title	Electrical Engineer	Title	Technical Director

Contents

Appendices

Figures

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1 Introduction

1.1 Background

This report forms part of the 2020 Soil Survey, which in turn forms part of the Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam. The objective of Post Feasibility Bridging Study is to provide recommendations on the bulk conveyance infrastructure required for the equitable distribution of the existing and additional water from the raised Clanwilliam Dam.

The specific project that this report is related to is for proposed installation of an underground water pipe leading out of the raised Clanwilliam Dam. This report documents the testing process and results to determine the soil electrical resistivity of the soil along the proposed route.

2 Technical Information

2.1 Soil Electrical Resistivity

Historically, soil electrical resistivity measurements have been used as an indicator of soil corrosivity. A high soil electrical resistivity will usually slow down corrosive reactions by limiting the ionic current flow associated with soil corrosion.

Soil composition, concentrations of ionic soluble salt, moisture content, and temperature all impact the soil electrical resistivity. One can make an estimation on soil electrical resistivity based on soil classification, but soil is rarely homogenous, and the resistivity of the soil will vary geographically and at different soil depths. Due to the variations in soil, estimation of soil resistivity based on soil classification would only provide a rough approximation. Actual resistivity measurements, like those presented in this site soil investigation, are required to fully quantify the resistivity and hence allow the designer to cater for the expected corrosivity of the installation environment.

3 Measurement Methodology

Soil electrical resistivity is usually measured using either the Four-Pin Wenner Method or the Two-Pin Shepard's Canes Method, with the most common being the former. The Four-Pin Wenner method [1] was developed by Dr Frank Wenner of the U.S. Bureau of Standards in 1915 and has been used ever since.

This site analysis utilised the Four-Pin Wenner Method.

3.1 Four-Pin Method (Wenner Method)

The Wenner Method uses four electrodes, two for current injection and two for voltage measurement. The four electrodes are embedded into the ground in a straight line, equidistant from each other as shown in Figure 1. The apparent resistivity (ρ_E) is a function derived from the measured potential difference between the centre pair of pins (P1 and P1), while current is flowing between the two outside pins (C1 and C2). The method assumes that the measured resistivity is a measure of the hemispherical volume of earth between the two centre pins, Figure 2 graphically shows this principle.

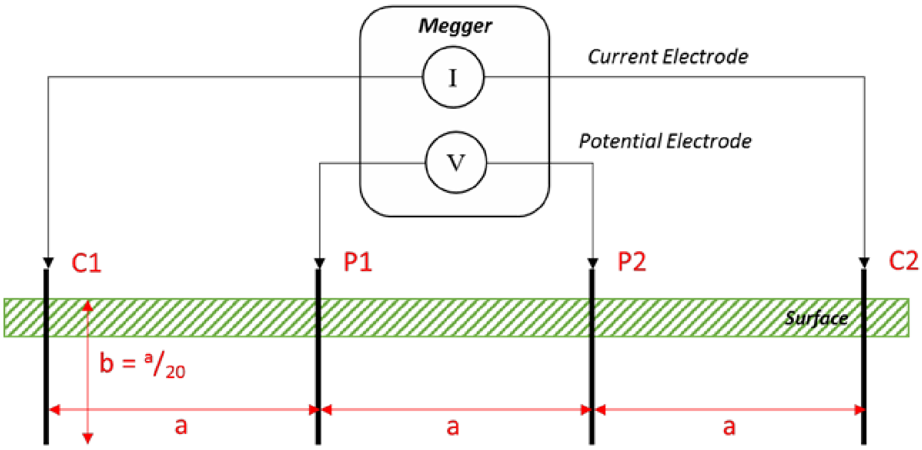

Figure 1 – Four-Pin Wenner Arrangement

Using the Wenner method, the apparent soil resistivity value can be realised by:

$$\rho_E = \frac{4 \cdot \pi \cdot a \cdot R_W}{1 + \frac{2 \cdot a}{\sqrt{a^2 + 4 \cdot b^2}} - \frac{a}{\sqrt{a^2 + b^2}}} \qquad (1)$$

Where ρ_E is the measured apparent soil resistivity [Ωm].

a is the electrode spacing [m]

b is the depth of the electrodes [m] (maximum value of $\frac{a}{20}$)

R_W is the Wenner resistance measured as $\frac{V}{I}$ in Figure 1 [Ω]

If b is small compared to a, as is the case of probes penetrating the ground only for a short distance (as normally happens), the previous equation can be reduced to:

$$\rho_E = 2 \cdot \pi \cdot a \cdot R_W \qquad (2)$$

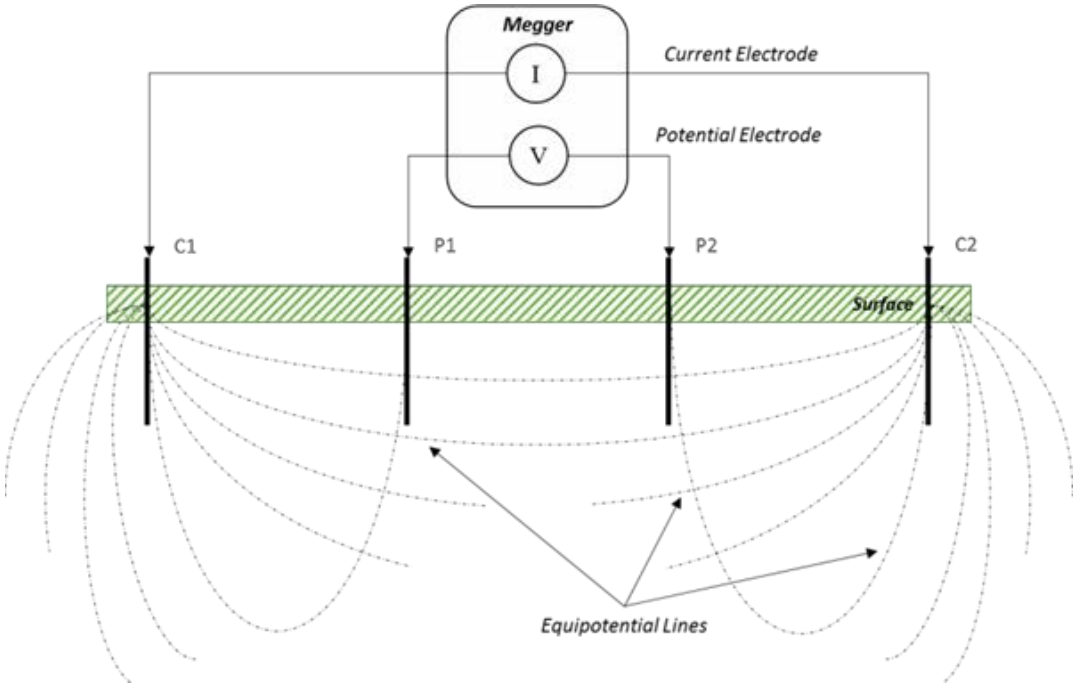

Figure 2 – Four-Pin Wenner Methodology Principle

3.2 Methodology

The following testing methodology was applied, utilising the Four-Pin Wenner Method for measuring the soil resistivity:

1. The testing location was identified, exact location of test recorded with GPS device (location along the proposed pipeline route).
2. The earth resistivity measurement device (Megger DET2/2) is placed in the centre position and the current and potential probes are prepared for installation as indicated in Figure 1 above.
3. The distance between the probes was measured with a tape measure to ensure that the probe spacing was accurate and that they were equidistance apart for each measurement.
4. The probes were driven into the ground to a depth of b, ensuring good contact was made between the soil and the probes.
5. For each spacing (a) the resistance reading on the megger was recorded.
6. The test was conducted in two directions, perpendicular to each other with the centre point of the location being kept the same while the distance between the probes increases.

4 Summary of Site Survey

Six site test locations were requested, two additional tests were conducted to verify results. The GPS coordinates of each of the site tests can be found on the respective Soil Resistivity Test Sheets found in Appendix B. These test locations are shown graphically in Figure 3.

Figure 3 – Location of conducted resistivity tests

Table 1: Soil Resistivity Test Results in Ω.m for the Clanwilliam Dam Test Locations

Probe Spacing	LOC1		LOC2		LOC3		LOC4	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
1	181	269	10	8	10	9	653	571
2	78	85	16	14	22	19	196	150
3	57	80	21	18	22	27	95	84
5	50	62	19	20	36	38	88	89
Trend	Decreasing		Increasing		Increasing		Decreasing	
Probe Spacing	**LOC5**		**LOC6**		**LOC7**		**LOC8**	
	Test 1	**Test 2**	**Test 1**	**Test 2**	**Test 1**	**Test 2**	**Test 1**	**Test 2**
1	3142	2218	1483	1521	1521	2708	487	360
2	2200	2373	557	970	1405	1571	200	265
3	2175	1915	447	603	1943	1269	114	188
5	1458	842	519	519	1847	1901	118	90
Trend	Decreasing		Decreasing		Increasing		Decreasing	

The pipeline will be installed at a depth of 3 m, so for each location the average of the two perpendicular test measurements at the 3 m spacing is shown in Figure 4. Figure 4 shows locations in order from left to right, as they appear in Figure 3, following the proposed pipeline route.

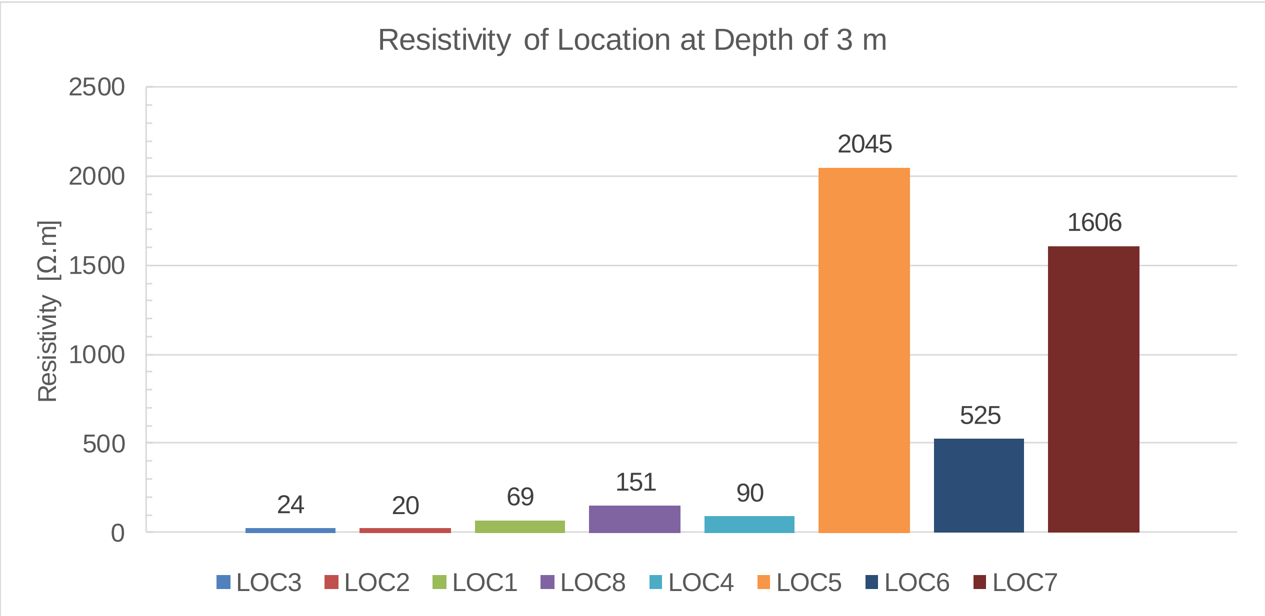

Figure 4 – Measured Soil Resistivity at 3 m Depth

Based on the corrosion classification by [2] locations 3 and 2 are “highly corrosive”. Locations 1 and 4 are “moderately corrosive”, location 8 is “mildly corrosive”, and locations 5, 6, and 7, are “essentially noncorrosive. However, these are only based on the electrical measurement and can be refined using the data retrieved from the test pits.

Table 2: Corrosivity Classification [2]

Soil Resistivity [Ω.m]	Corrosivity Rating
>200	Essentially noncorrosive
100 to 200	Mildly corrosive
50 to 100	Moderately corrosive
30 to 50	Corrosive
10 to 30	Highly corrosive
<10	Extremely corrosive

5 Conclusion

Site measurements at the Clanwilliam Dam site vary quite largely along the route with classifications of soil ranging from highly corrosive to essentially noncorrosive. The electrical soil resistivity test results should be used together with the site test pit data to refine the assigned classifications and improve understanding of the soil conditions expected along the pipeline route.

6 Bibliography

[1] F. Wenner, “A Method of Measuring Earth Resistivity,” in *Bulletin of Bureau of Standards Vol. 18*, Washington, U.S Bureau of Standards, 1915, pp. 469-478.

[2] P. R. Roberge, Corrosion Engineering: Principles and Practice, New York: McGraw-Hill, 2008.

Appendix A. Meggar Calibration Certificate

KoCoS
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KoCoS Calibration Service

CALIBRATION CERTIFICATE

Calibration Laboratory
KoCoS Measurement & Control (PTY) LTD
Cape Town

This certificate is issued in accordance with the conditions of the KoCoS Calibration Service. It is a correct record of the measurements made. This certificate may not be produced other than in full, except with written approval of the issuing laboratory.

The values in this certificate are correct at the time of calibration. Subsequently the accuracy will depend on such factors as the care exercised in handling and use of the instrument, and the frequency of use. Re-calibration should be performed after a period that has been chosen to ensure that the instrument's accuracy remains within the prescribed limits.

The laboratory is environmentally controlled at a temperature of 23 °C ± 2 °C and a relative humidity between 35% and 60%.

The uncertainties of measurements are quoted in terms of a 95% (2σ) confidence level.

Calibration of	: Auto Earth Tester
Make	: Megger
Model	: DET2/2
Serial No	: 101398068
Calibrated for	: Aurecon South Africa
Calibration Equipment	: CT01100 & Range of Standard Resistors
Calibration Procedure	: KP0140
Recommended Recalibration Date	: 06-03-2021

Date of Issue : 06-03-2020

Authorised by: H Erwin

Certificate No : KC9443

Date of Calibration: 06-03-2020

Page 1 of 2 pages

Calibrated by: J Bester

Calibration Laboratory, 40 Jeanette Street, Brackenfell, 7560 / PO Box 3585, Durbanville, 7551
Telephone: Local 021-982 0016, International +27 21 982 0016 **Fax**: Local 021-982 0230, International +27 21 982 0230
E-mail: sales@kocos.co.za website: www.kocos.co.za

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KoCoS Calibration Service

1. PROCEDURE

The Auto Earth Tester was calibrated in terms of laboratory standards, the results of which were traceable to national measuring standards maintained at the NMISA.

2. RESULTS

Following are the results as recorded during the calibration process.

2.1 Resistance

Actual Resistance (Ω)	Indication (Ω)
0,0100 Ω	< 0,01 Ω
0,1000 Ω	0,098 Ω
1,0000 Ω	1,000 Ω
10,000 Ω	10,01 Ω
100,00 Ω	100,0 Ω
1,0000 kΩ	1,000 kΩ
10,00 kΩ	10,00 kΩ

Uncertainty of measurement: ± (0,1% + 1 digit)

3. REMARKS

Only the above results were recorded.

--End of Certificate--

Certificate No : KC9443

Date of Calibration: 06-03-2020

Calibrated by: J Bester

Calibration Laboratory, 40 Jeanette Street, Brackenfell, 7560 / PO Box 3585, Durbanville, 7551
Telephone: Local 021-982 0016, International +27 21 982 0016 Fax: Local 021-982 0230, International +27 21 982 0230
E-mail: sales@kocos.co.za website: www.kocos.co.za

Appendix B. Test Results

The results are detailed as follows:

a) Date, location and site conditions

b) Soil resistivity measurements

c) Graph of results

All tests performed by:

- Craig MacDonald (Electrical Engineer)
- Paul McQueen (Electrical Engineer)

Appendix C. Clanwilliam Dam Location 1

Soil Resistivity Measurement Test (Wenner Method)

DETAILS **LOC1**

Client's Name:	Department of Water and Sanitation
Project Name:	Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam (WP0485)
Project No:	113834
Date of test:	03-08-2020
Location:	Clan William Dam (LOC1)
Co-ordinates:	32°11'55.8"S 18°53'38.6"E
Weather:	Clear, Temperaure 19°/9°C, Humidity 50%, Barometer 1021 mbar
Soil:	Dry Sandstone, scattered rocks
S/N of earth resistance tester:	S/N:101398068 Cert No: KC9443
Calibrated (Yes/No):	Yes

SURVEY RESULTS TABLE

			Test 1		Test 2		Mean
Probe Spacing a (m)	Specific Depth D = 0,8a (m)	Geometric factor K K = 2πa	Tester Reading R (Ω)	Resistivity p = RK (Ω.m)	Tester Reading R (Ω)	Resistivity p = RK (Ω.m)	Resistivity p = RK (Ω.m)
1	0.8	6.28	28.80	180.96	42.80	268.92	224.94
2	1.6	12.57	6.20	77.91	6.75	84.82	81.37
3	2.4	18.85	3.00	56.55	4.27	80.49	68.52
5	4	31.42	1.60	50.33	1.99	62.39	56.36

COMMENTS

None.

Figure 5 – Report Form for Location 1

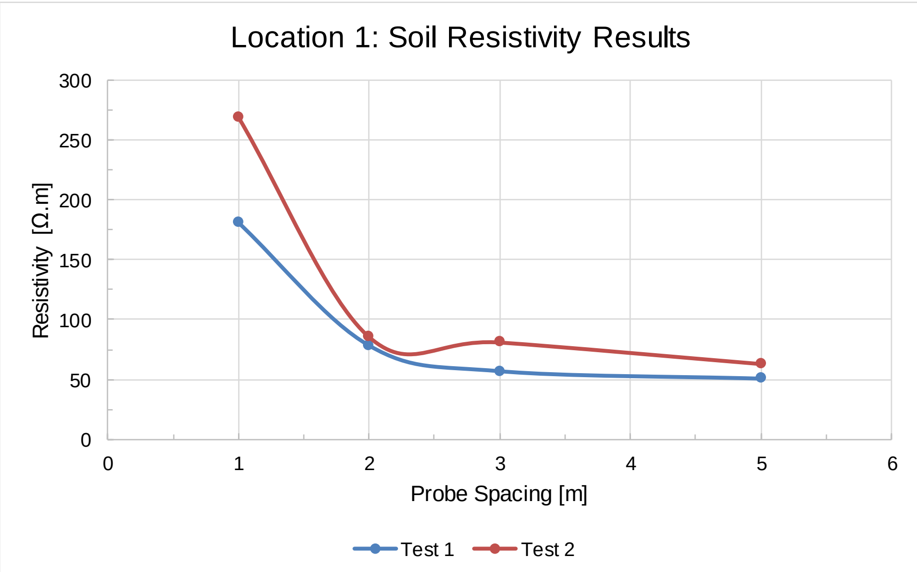

Figure 6 – Results from Test 1 and Test 2

Appendix D. Clanwilliam Dam Location 2

Soil Resistivity Measurement Test (Wenner Method)

DETAILS **LOC2**

Client's Name:	Department of Water and Sanitation
Project Name:	Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam (WP0485)
Project No:	113834
Date of test:	03-08-2020
Location:	Clan William Dam
Co-ordinates:	32°11'51.4"S 18°53'36.8"E
Weather:	Clear, Temperaure 19°/9°C, Humidity 50%, Barometer 1021 mbar
Soil:	Dry Sandstone, scattered rocks
S/N of earth resistance tester:	S/N:101398068 Cert No: KC9443
Calibrated (Yes/No):	Yes

SURVEY RESULTS TABLE

			Test 1		Test 2		Mean
Probe Spacing a (m)	Specific Depth D = 0,8a (m)	Geometric factor K K = 2πa	Tester Reading R (Ω)	Resistivity p = RK (Ω.m)	Tester Reading R (Ω)	Resistivity p = RK (Ω.m)	Resistivity p = RK (Ω.m)
1	0.8	6.28	1.518	9.54	1.270	7.98	8.76
2	1.6	12.57	1.268	15.93	1.130	14.20	15.07
3	2.4	18.85	1.098	20.70	0.980	18.47	19.58
5	4	31.42	0.608	19.10	0.644	20.23	19.67

COMMENTS

None.

Figure 7 – Report Form for Location 2

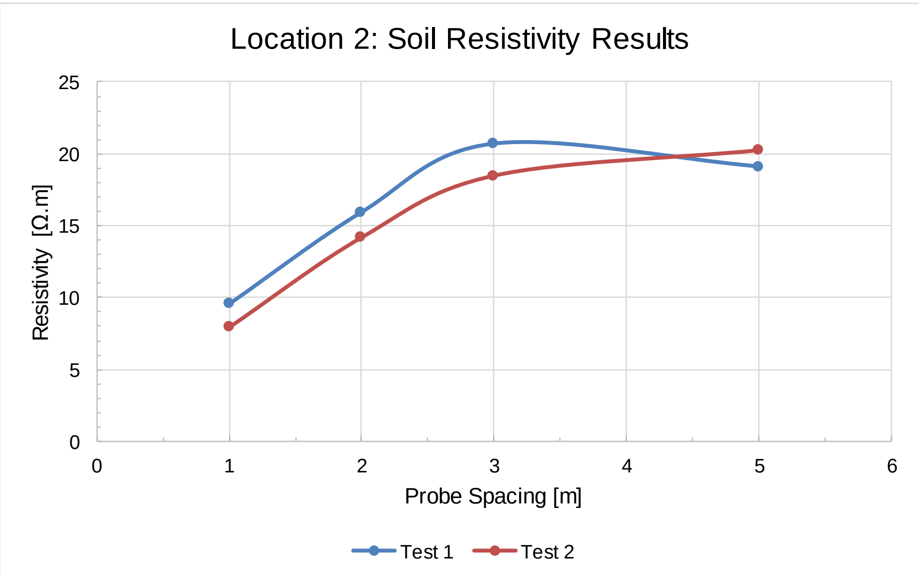

Figure 8 – Results from Test 1 and Test 2

Appendix E. Clanwilliam Dam Location 3

Soil Resistivity Measurement Test (Wenner Method)

DETAILS	**LOC3**
Client's Name:	Department of Water and Sanitation
Project Name:	Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam (WP0485)
Project No:	113834
Date of test:	03-08-2020
Location:	Clan William Dam
Co-ordinates:	32°11'49.5"S 18°53'35.5"E
Weather:	Clear, Temperaure 19°/9°C, Humidity 50%, Barometer 1021 mbar
Soil:	Dry Sandstone, scattered rocks
S/N of earth resistance tester:	S/N:101398068 Cert No: KC9443
Calibrated (Yes/No):	Yes

SURVEY RESULTS TABLE

			Test 1		Test 2		Mean
Probe Spacing a (m)	Specific Depth D = 0,8a (m)	Geometric factor K K = 2πa	Tester Reading R (Ω)	Resistivity p = RK (Ω.m)	Tester Reading R (Ω)	Resistivity p = RK (Ω.m)	Resistivity p = RK (Ω.m)
1	0.8	6.28	1.566	9.84	1.442	9.06	9.45
2	1.6	12.57	1.714	21.54	1.50	18.85	20.19
3	2.4	18.85	1.158	21.83	1.42	26.80	24.32
5	4	31.42	1.134	35.63	1.21	38.14	36.88

COMMENTS

None.

Figure 9 – Report Form for Location 3

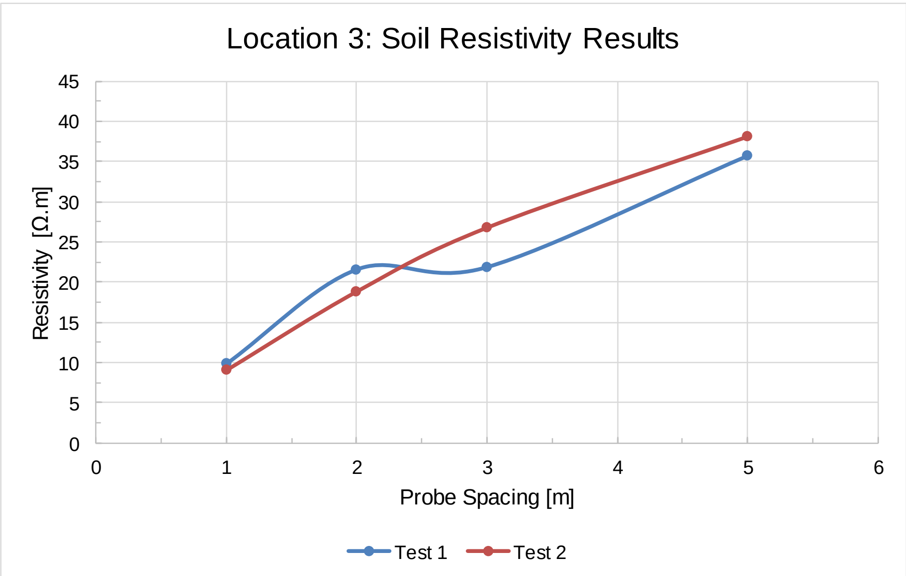

Figure 10 – Results from Test 1 and Test 2

Appendix F. Clanwilliam Dam Location 4

Soil Resistivity Measurement Test (Wenner Method)

DETAILS	LOC4
Client's Name:	Department of Water and Sanitation
Project Name:	Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam (WP0485)
Project No:	113834
Date of test:	03-08-2020
Location:	Clan William Dam
Co-ordinates:	32°12'25.6"S 18°53'52.0"E
Weather:	Clear, Temperaure 19°/9°C, Humidity 50%, Barometer 1021 mbar
Soil:	Dry Sandstone, scattered rocks
S/N of earth resistance tester:	S/N:101398068 Cert No: KC9443
Calibrated (Yes/No):	Yes

SURVEY RESULTS TABLE

			Test 1		Test 2		Mean
Probe Spacing a (m)	Specific Depth D = 0,8a (m)	Geometric factor K K = 2πa	Tester Reading R (Ω)	Resistivity p = RK (Ω.m)	Tester Reading R (Ω)	Resistivity p = RK (Ω.m)	Resistivity p = RK (Ω.m)
1	0.8	6.28	103.90	652.82	90.80	570.51	611.67
2	1.6	12.57	15.63	196.41	11.97	150.42	173.42
3	2.4	18.85	5.04	95.00	4.48	84.45	89.72
5	4	31.42	2.79	87.65	2.83	88.91	88.28

COMMENTS

None.

Figure 11 – Report Form for Location 4

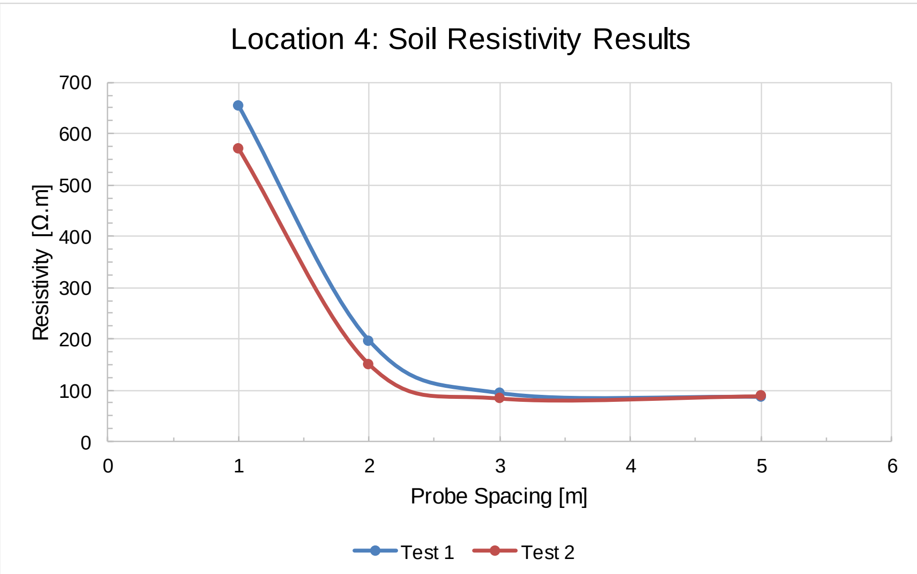

Figure 12 – Results from Test 1 and Test 2

Appendix G. Clanwilliam Dam Location 5

Soil Resistivity Measurement Test (Wenner Method)

DETAILS **LOC5**

Client's Name:	Department of Water and Sanitation
Project Name:	Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam (WP0485)
Project No:	113834
Date of test:	03-08-2020
Location:	Clan William Dam
Co-ordinates:	32°12'27.5"S 18°53'50.1"E
Weather:	Clear, Temperaure 19°/9°C, Humidity 50%, Barometer 1021 mbar
Soil:	Dry Sandstone, scattered rocks
S/N of earth resistance tester:	S/N:101398068 Cert No: KC9443
Calibrated (Yes/No):	Yes

SURVEY RESULTS TABLE

			Test 1		Test 2		Mean
Probe Spacing a (m)	Specific Depth D = 0,8a (m)	Geometric factor K K = 2πa	Tester Reading R (Ω)	Resistivity p = RK (Ω.m)	Tester Reading R (Ω)	Resistivity p = RK (Ω.m)	Resistivity p = RK (Ω.m)
1	0.8	6.28	500.00	3141.59	353.00	2217.96	2679.78
2	1.6	12.57	175.10	2200.37	188.80	2372.53	2286.45
3	2.4	18.85	115.40	2175.24	101.60	1915.11	2045.18
5	4	31.42	46.40	1457.70	26.80	841.95	1149.82

COMMENTS

When knocking in the pins, although they could easily enter the soil, one could hear a solid noise. Therefore it is expected that there is rock fairly close to the surface.

Figure 13 – Report Form for Location 5

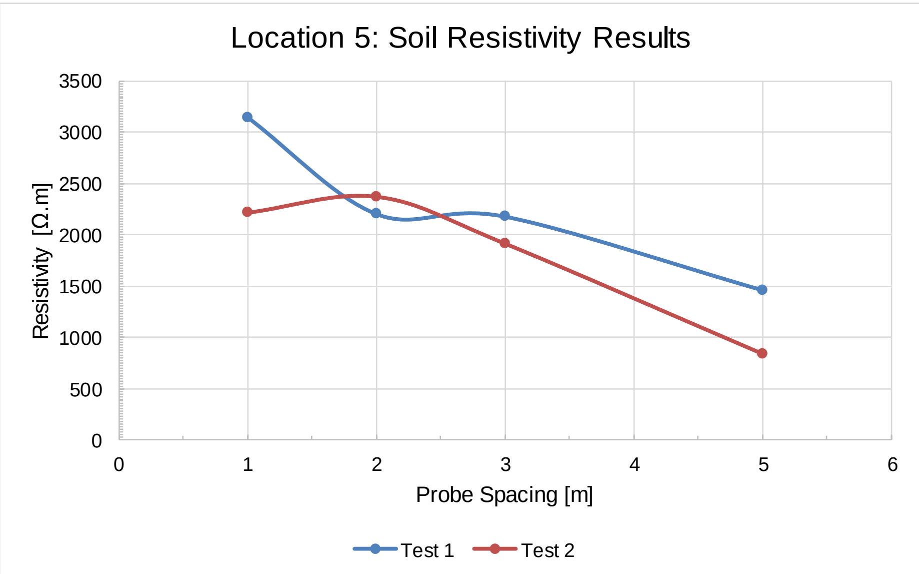

Figure 14 – Results from Test 1 and Test 2

Appendix H. Clanwilliam Dam Location 6

Soil Resistivity Measurement Test (Wenner Method)

DETAILS	**LOC6**
Client's Name:	Department of Water and Sanitation
Project Name:	Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam (WP0485)
Project No:	113834
Date of test:	03-08-2020
Location:	Clan William Dam
Co-ordinates:	32°12'31.7"S 18°53'45.8"E
Weather:	Clear, Temperaure 19°/9°C, Humidity 50%, Barometer 1021 mbar
Soil:	Dry Sandstone, scattered rocks
S/N of earth resistance tester:	S/N:101398068 Cert No: KC9443
Calibrated (Yes/No):	Yes

SURVEY RESULTS TABLE

			Test 1		Test 2		Mean
Probe Spacing a (m)	**Specific Depth D = 0,8a (m)**	**Geometric factor K K = 2πa**	**Tester Reading R (Ω)**	**Resistivity p = RK (Ω.m)**	**Tester Reading R (Ω)**	**Resistivity p = RK (Ω.m)**	**Resistivity p = RK (Ω.m)**
1	0.8	6.28	236.00	1482.83	242.00	1520.53	1501.68
2	1.6	12.57	44.30	556.69	77.20	970.12	763.41
3	2.4	18.85	23.70	446.73	32.00	603.19	524.96
5	4	31.42	16.52	518.99	16.53	519.31	519.15

COMMENTS

None.

Figure 15 – Report Form for Location 6

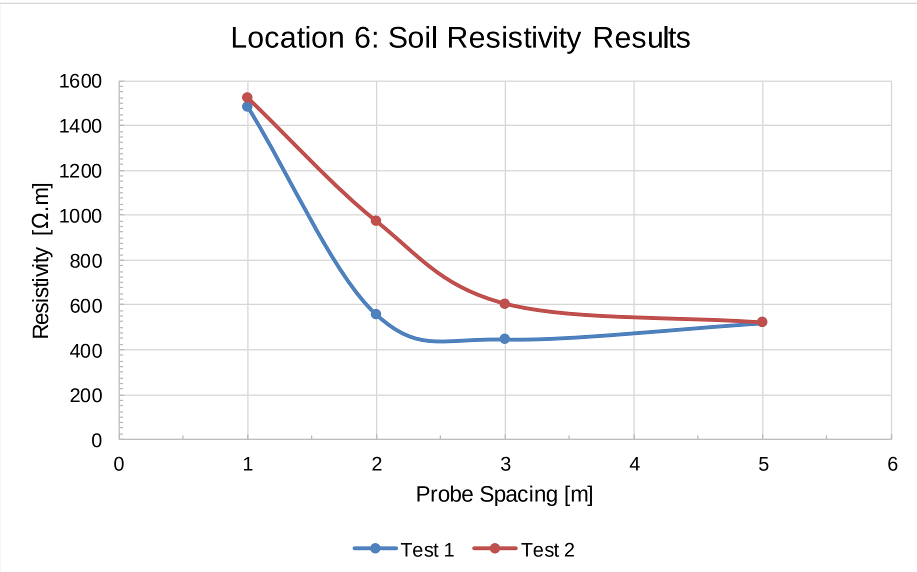

Figure 16 – Results from Test 1 and Test 2

Appendix I. Clanwilliam Dam Location 7

Soil Resistivity Measurement Test (Wenner Method)

DETAILS | **LOC7**

Client's Name:	Department of Water and Sanitation
Project Name:	Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam (WP0485)
Project No:	113834
Date of test:	03-08-2020
Location:	Clan William Dam
Co-ordinates:	32°12'32.2"S 18°53'44.1"E
Weather:	Clear, Temperaure 19°/9°C, Humidity 50%, Barometer 1021 mbar
Soil:	Dry Sandstone, scattered rocks
S/N of earth resistance tester:	S/N:101398068 Cert No: KC9443
Calibrated (Yes/No):	Yes

SURVEY RESULTS TABLE

			Test 1		Test 2		Mean
Probe Spacing a (m)	Specific Depth D = 0,8a (m)	Geometric factor K K = 2πa	Tester Reading R (Ω)	Resistivity p = RK (Ω.m)	Tester Reading R (Ω)	Resistivity p = RK (Ω.m)	Resistivity p = RK (Ω.m)
1	0.8	6.28	242.00	1520.53	431.00	2708.05	2114.29
2	1.6	12.57	111.80	1404.92	125.00	1570.80	1487.86
3	2.4	18.85	103.10	1943.39	67.30	1268.58	1605.98
5	4	31.42	58.80	1847.26	60.50	1900.66	1873.96

COMMENTS

When knocking in the pins, although they could easily enter the soil, one could hear a solid noise.
Therefore it is expected that there is rock fairly close to the surface.

Figure 17 – Report Form for Location 7

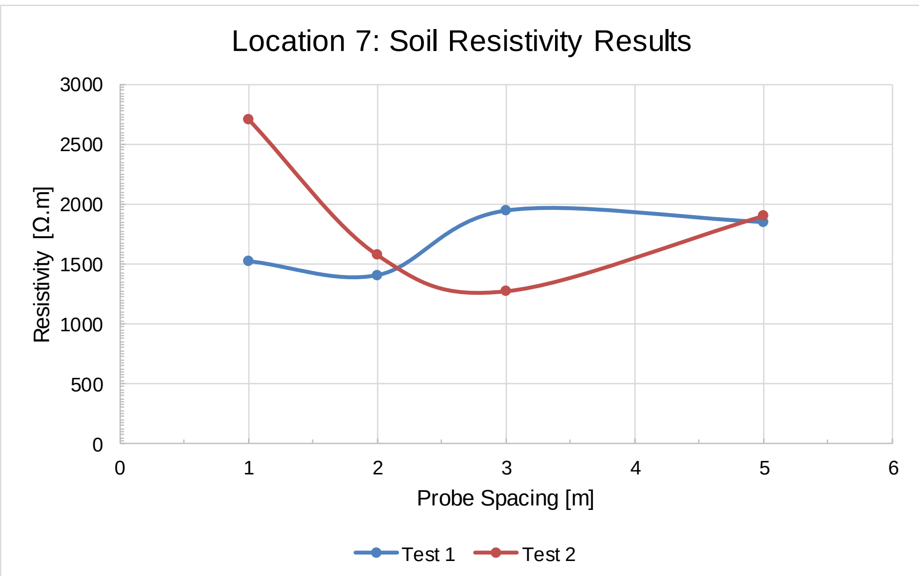

Figure 18 – Results from Test 1 and Test 2

Appendix J. Clanwilliam Dam Location 8

Soil Resistivity Measurement Test (Wenner Method)

DETAILS **LOC8**

Client's Name:	Department of Water and Sanitation
Project Name:	Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam (WP0485)
Project No:	113834
Date of test:	03-08-2020
Location:	Clan William Dam
Co-ordinates:	32°12'23.8"S 18°53'54.0"E
Weather:	Clear, Temperaure 19°/9°C, Humidity 50%, Barometer 1021 mbar
Soil:	Dry Sandstone, scattered rocks
S/N of earth resistance tester:	S/N:101398068 Cert No: KC9443
Calibrated (Yes/No):	Yes

SURVEY RESULTS TABLE

			Test 1		Test 2		Mean
Probe Spacing a (m)	Specific Depth D = 0,8a (m)	Geometric factor K K = 2πa	Tester Reading R (Ω)	Resistivity p = RK (Ω.m)	Tester Reading R (Ω)	Resistivity p = RK (Ω.m)	Resistivity p = RK (Ω.m)
1	0.8	6.28	77.50	486.95	57.30	360.03	423.49
2	1.6	12.57	15.93	200.18	21.10	265.15	232.67
3	2.4	18.85	6.05	114.04	9.98	188.12	151.08
5	4	31.42	3.75	117.81	2.85	89.54	103.67

COMMENTS

None.

Figure 19 – Report Form for Location 8

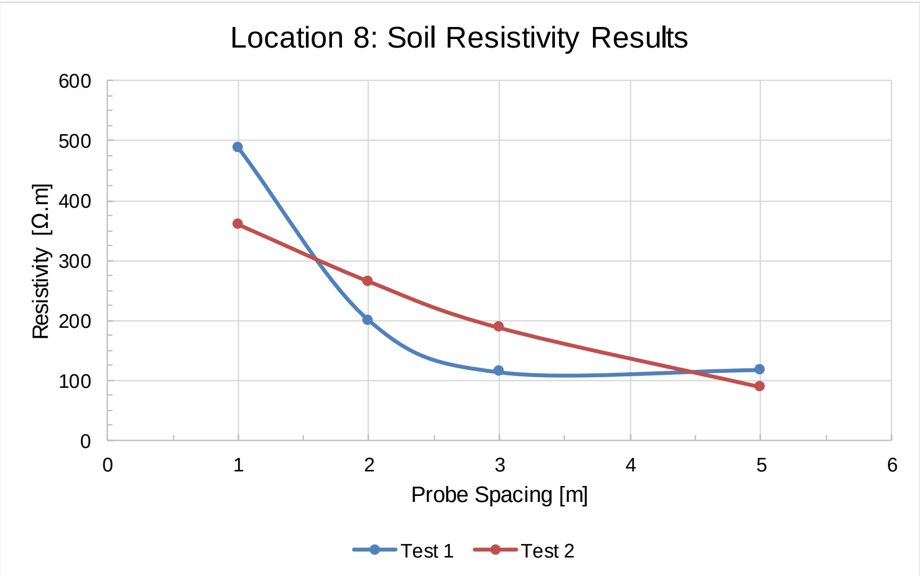

Figure 20 – Results from Test 1 and Test 2

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Appendix G
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")

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Report No: 2011-002 (Rev 1.01)

Olifants River, Clanwilliam Dam

Table of Content

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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:

……………………………………………………………………………………………

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.

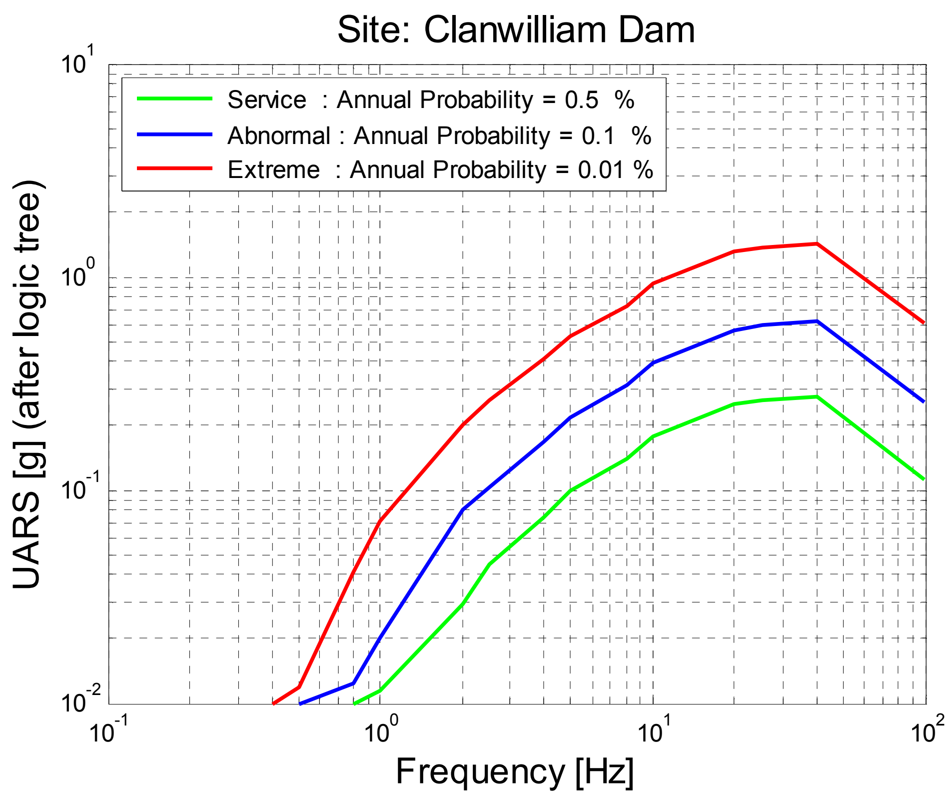
The PSHA was performed using conventional, Cornell-McGuire procedure (Cornell, 1968; McGuire, 1976; 1978), where the integration across the uncertainty in the PGA prediction equation is an integral part of the methodology.

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

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3.1. List of Figures

(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.

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.

Figure 9.4(a). Uniform Acceleration Response Spectra (horizontal component) in terms of ground motion vibration frequency, 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 9.4(b). Uniform Acceleration Response Spectra (horizontal component) in terms of ground motion vibration frequency, 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 9.4 (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

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.

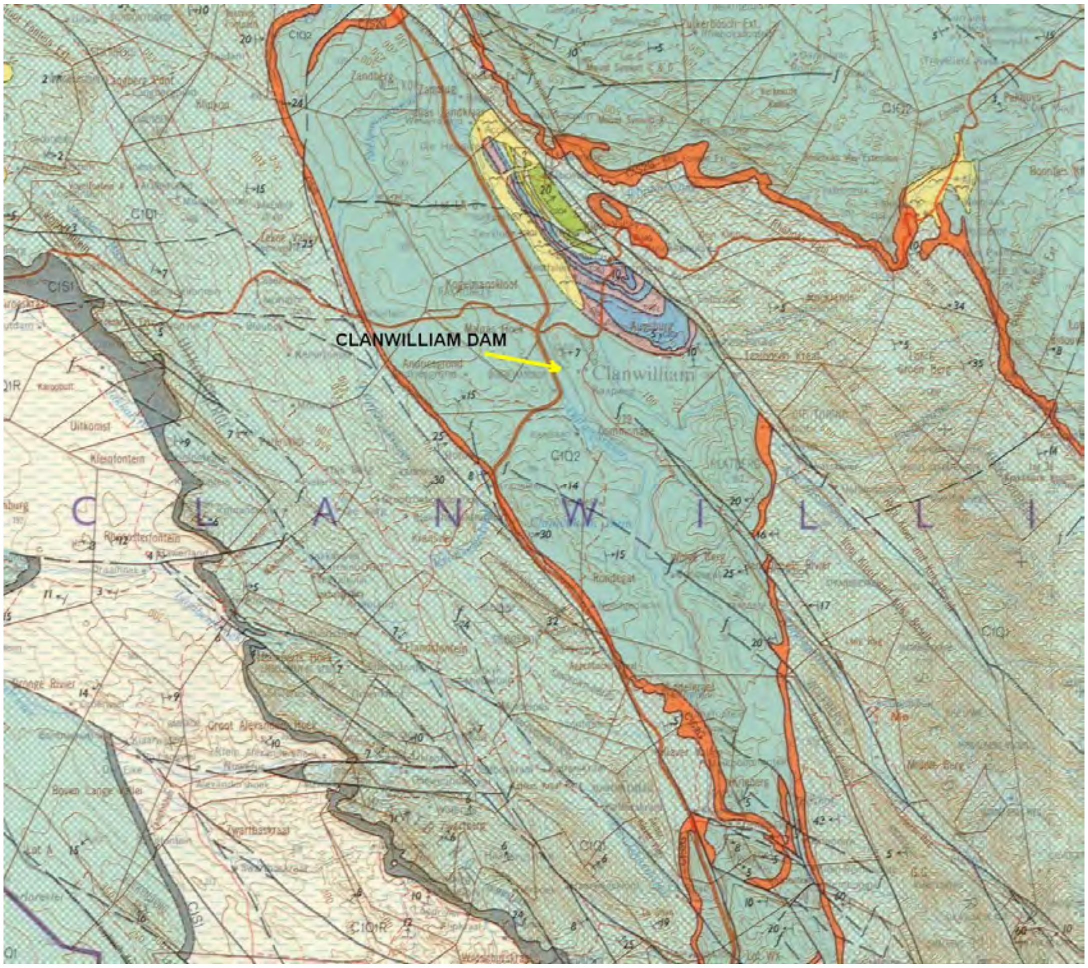

Figure 6.1. Regional geological setting; from the 1:250 000 geological map, Sheet 3218 Clanwilliam (Council for Geoscience, Pretoria).

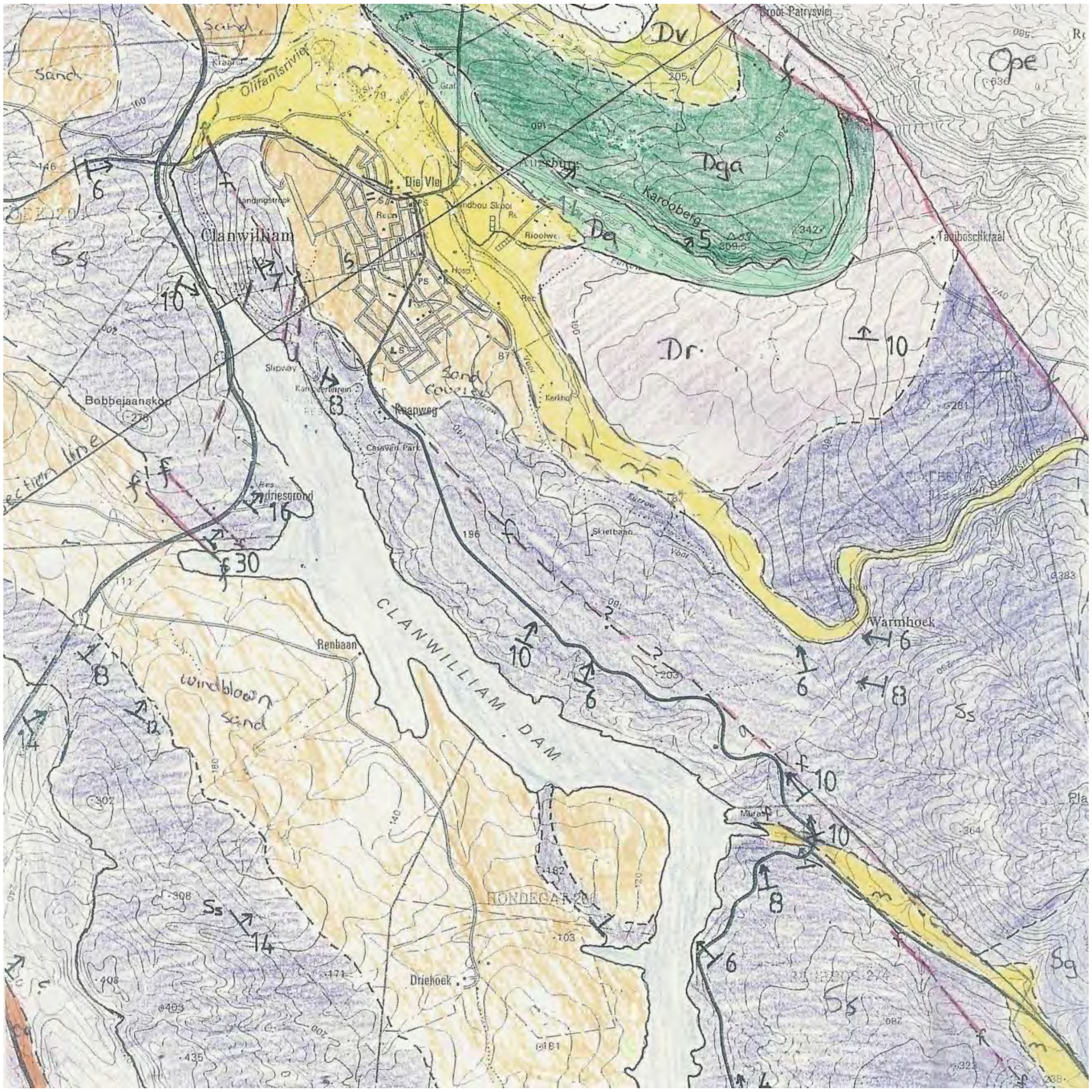

Figure 6.2. Regional geology of the Clanwilliam Dam environs (after 1:50 000 geological field sheet – Council for Geoscience, Pretoria).

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.

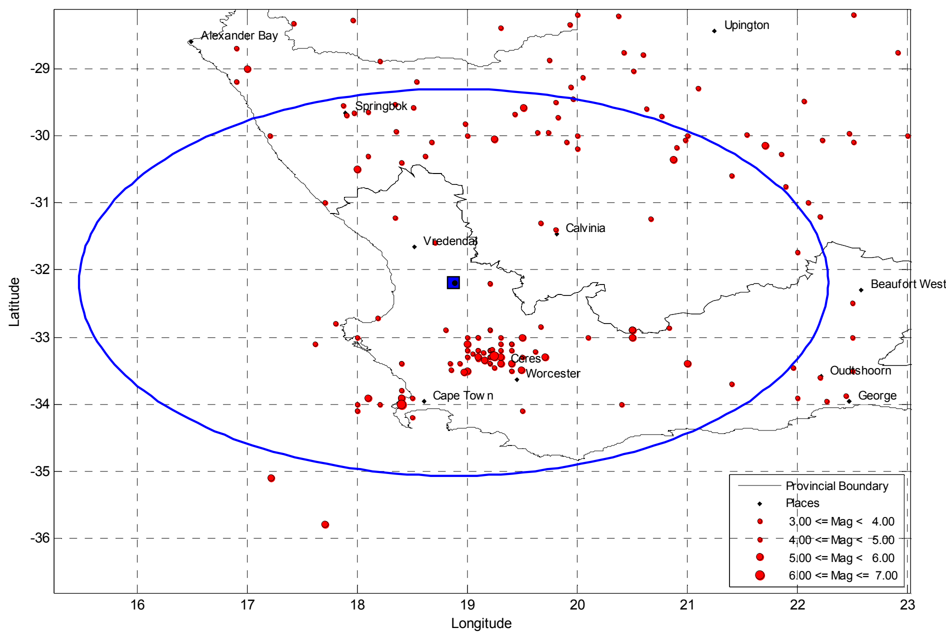

Figure 7.1 Distribution of largest seismic events within 320 km radius of the Clanwilliam Dam site used in the study. The location of dam wall is shown as a blue square.

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.

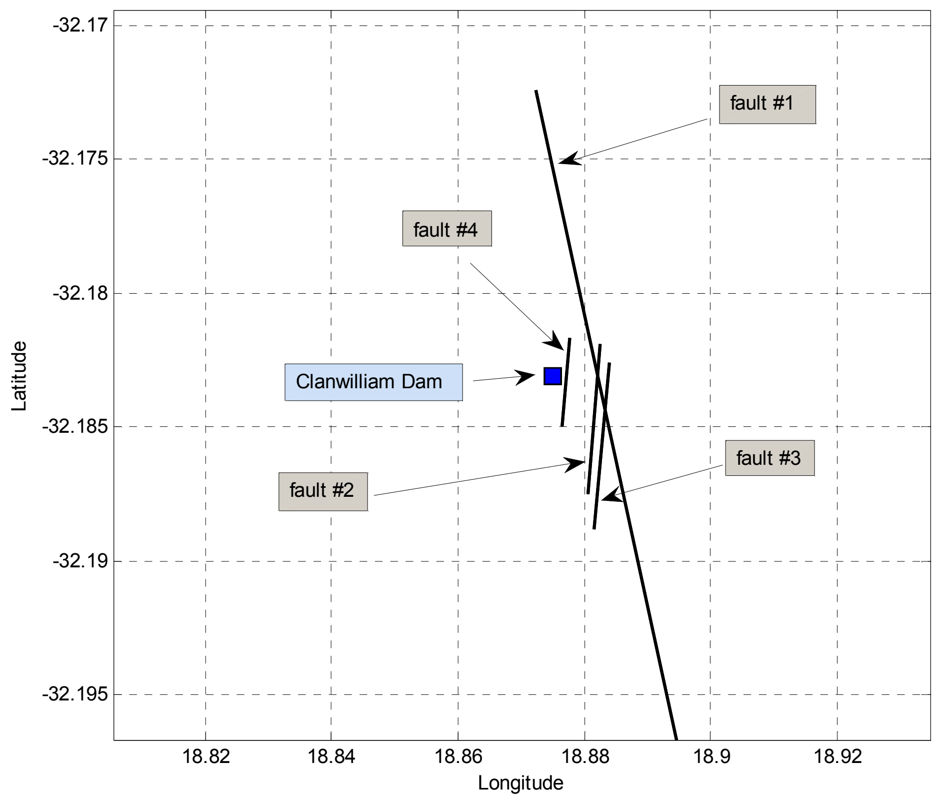

Figure 7.2 Close-up view of four faults in vicinity of Clanwilliam Dam (G. Davis, personal communication). The location of dam wall is shown as a blue square.

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.

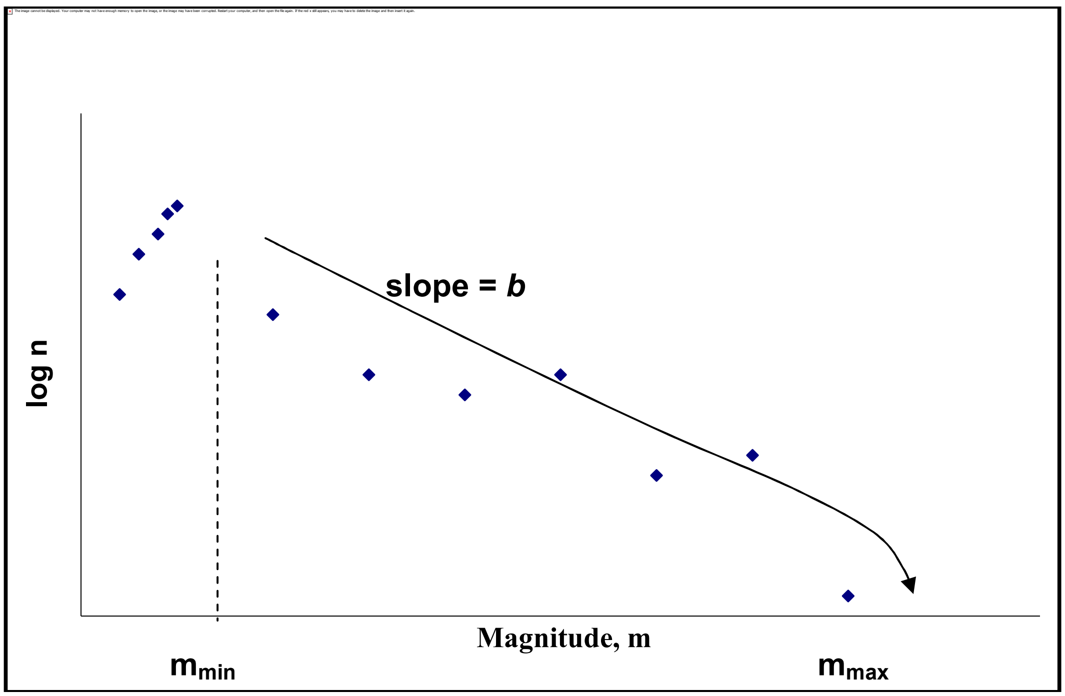

Figure 7.3 Schematic illustration of the doubly truncated frequency-magnitude Gutenberg-Richter relation. The slope of the curve is described by parameter b, known as the b-value of the Gutenberg-Richter. Value $m_{\min}$ is the minimum earthquake magnitude to be considered and $m_{\max}$ is the regional 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

$$\lambda = \frac{Number\ of\ earthquakes\ with\ m \geq m_{\min}}{Time\ span\ of\ observations}\ , \tag{7.3}$$

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

$$a = \log_{10} \lambda + b \cdot m_{\min} \quad (7.4)$$

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.

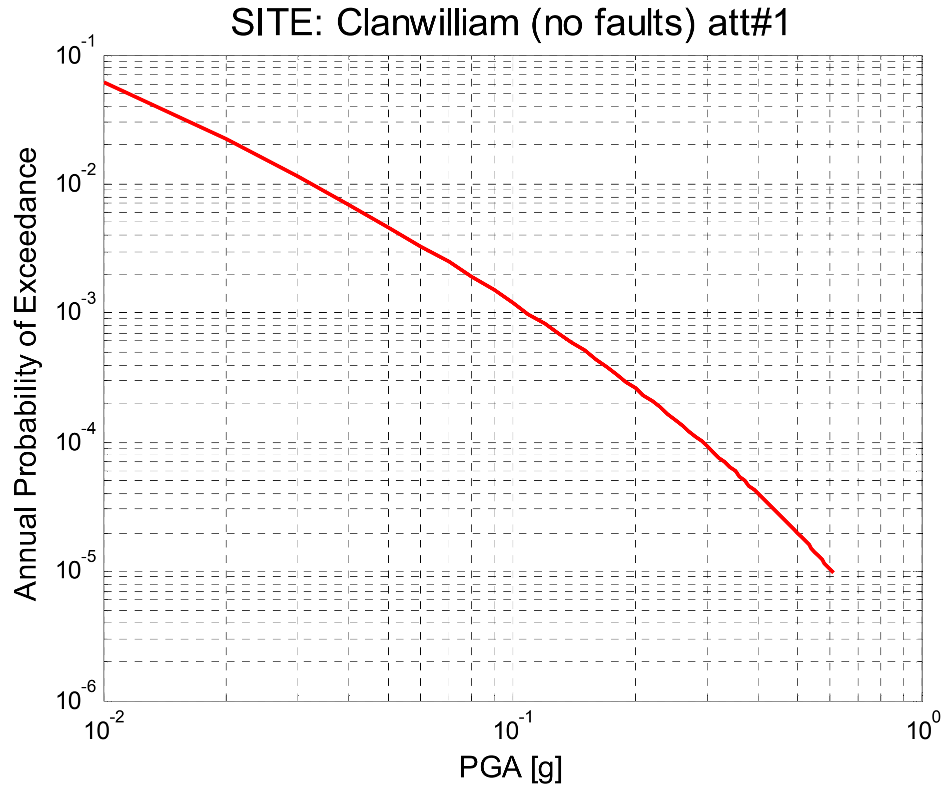

Figure 9.1(a) Annual probability of exceedance of median value of horizontal PGA at the site of the dam, calculated for ground motion prediction equation by Atkinson and Boore (2006), (GMPE-1). Scenario #1: four known faults in vicinity of the dam are not active.

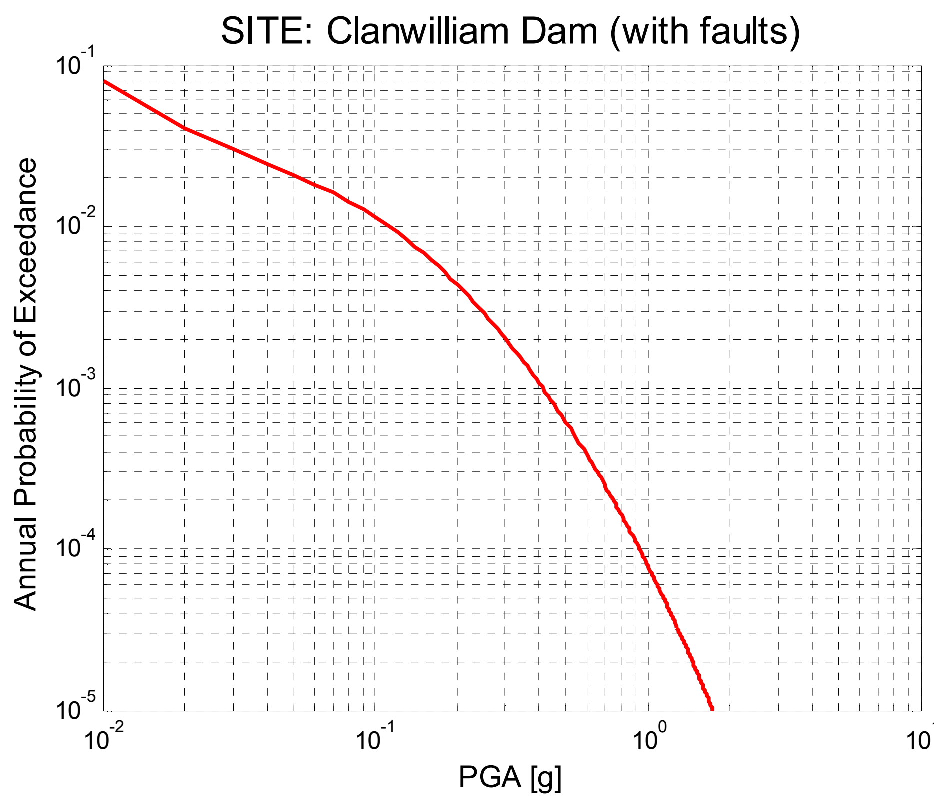

Figure 9.1(b) Annual probability of exceedance of median value of horizontal PGA at the site of the dam, calculated for ground motion prediction equation by Atkinson and Boore (2006), (GMPE-1). Scenario #2: four known faults in vicinity of the dam are active.

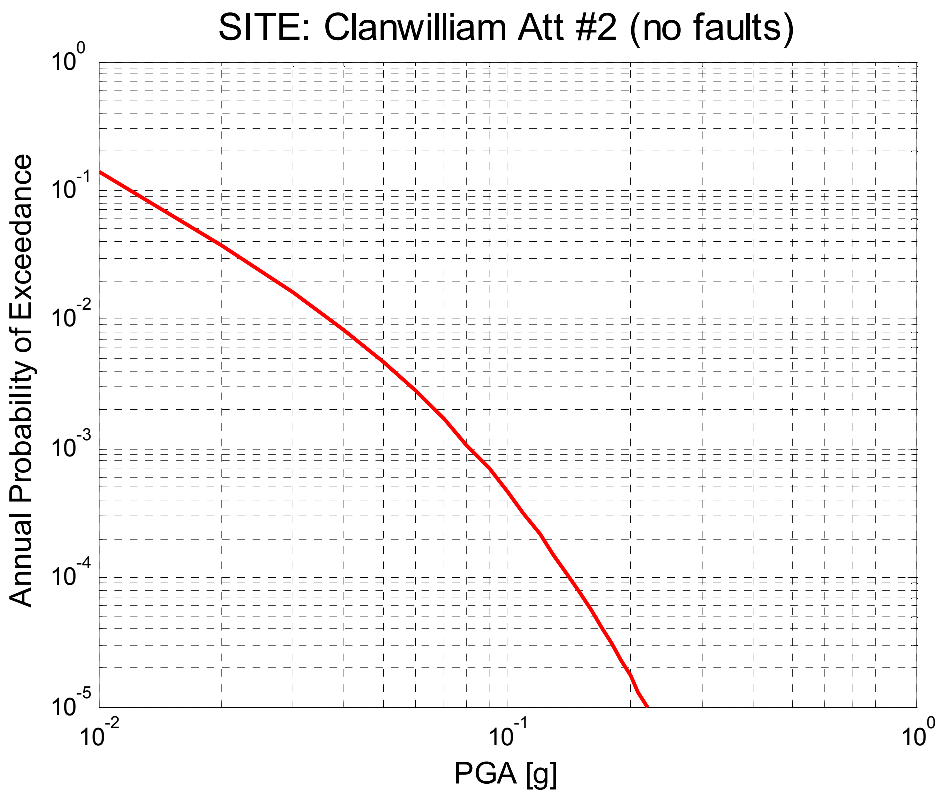

Figure 9.1(c) Annual probability of exceedance of median value of horizontal PGA at the site of the dam, calculated for ground motion prediction equation by Spudich *et al.* (1999), (GMPE-2). Scenario #1: four known faults in vicinity of the dam are not active.

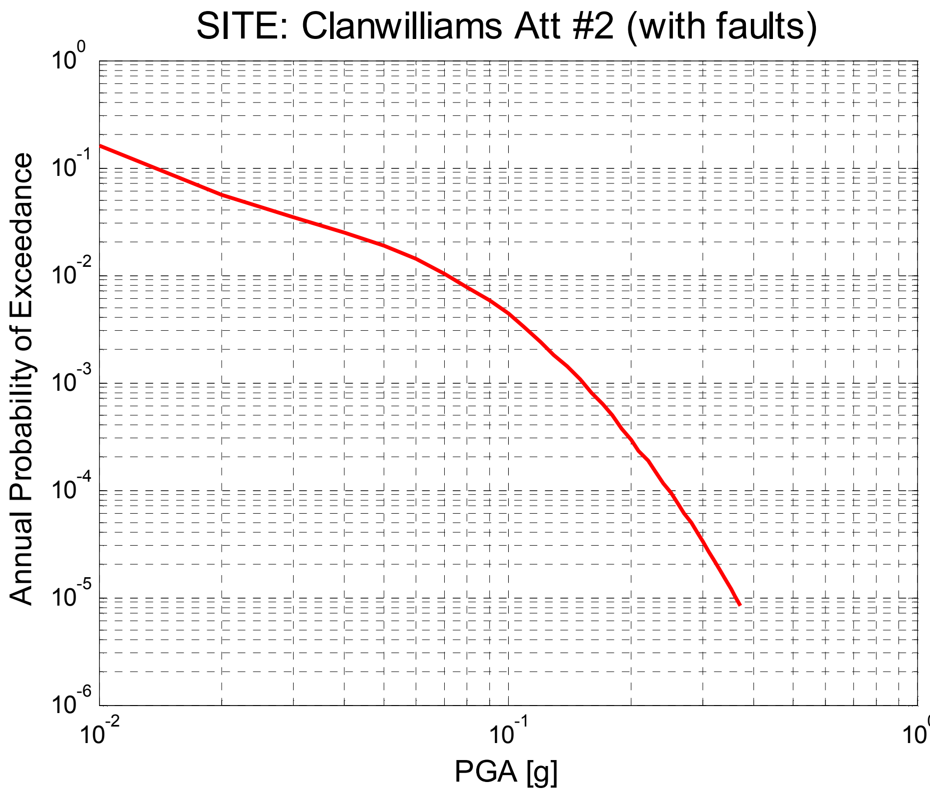

Figure 9.1(d) Annual probability of exceedance of median value of horizontal PGA at the site of the dam, calculated for ground motion prediction equation by Spudich *et al.* (1999), (GMPE-2). Scenario #2: four known faults in vicinity of the dam are active.

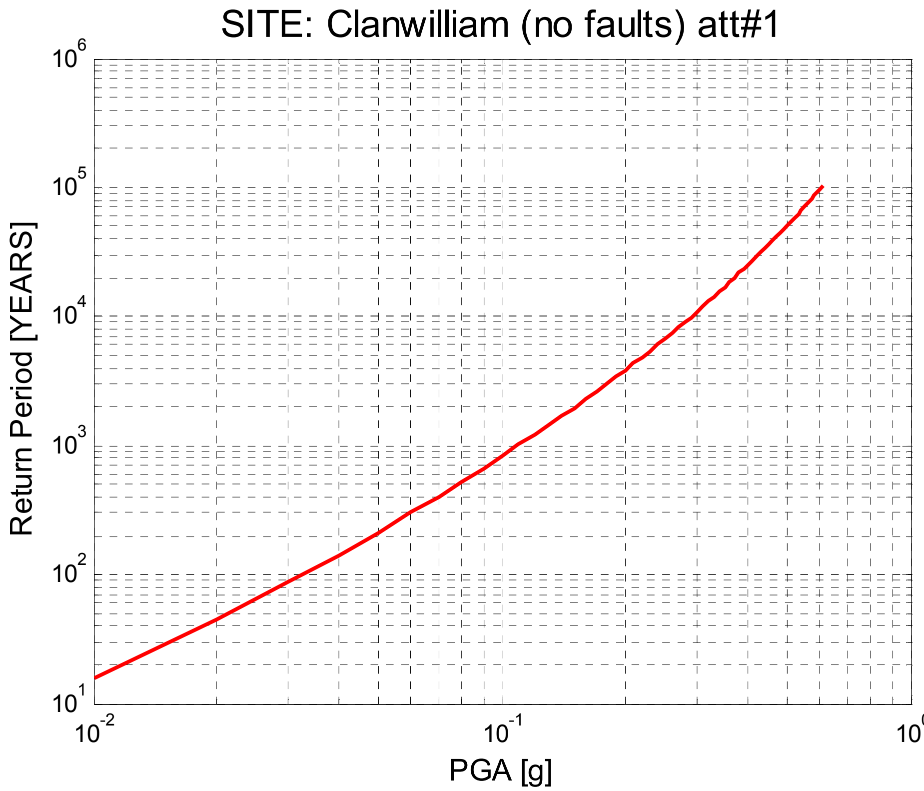

Figure 9.2(a) Mean return period of median value of horizontal PGA at the site of the dam, calculated for ground motion prediction equation by Atkinson and Boore (2006), (GMPE-1). Scenario #1: four known faults in vicinity of the dam are not active.

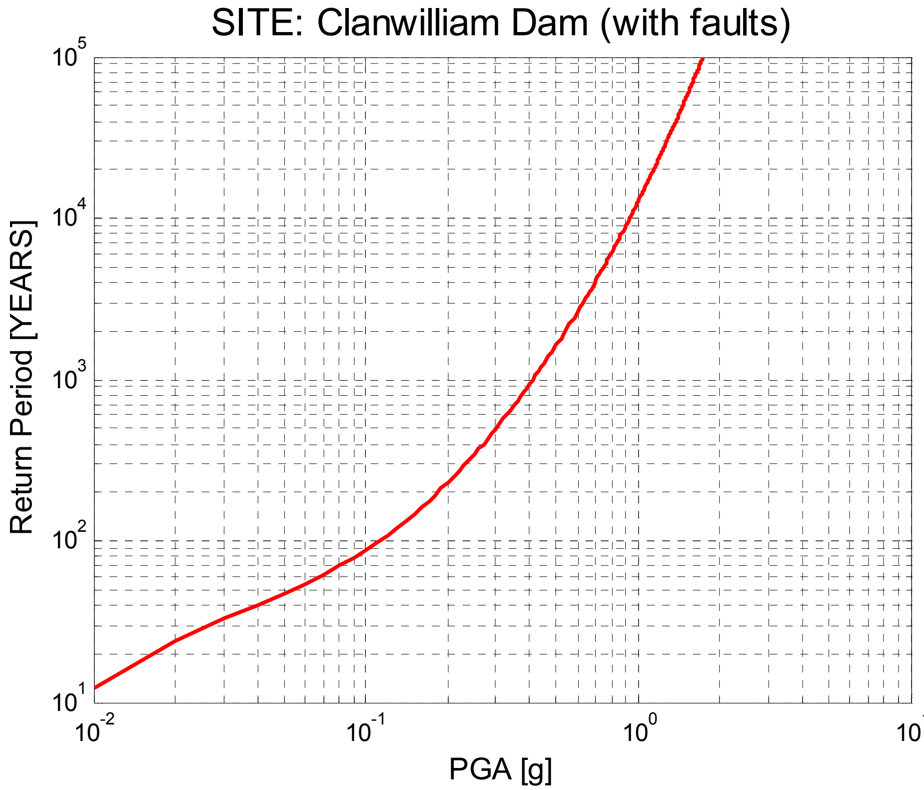

Figure 9.2(b) Mean return period of median value of horizontal PGA at the site of the dam, calculated for ground motion prediction equation by Atkinson and Boore (2006), (GMPE-1). Scenario #2: four known faults in vicinity of the dam are active.

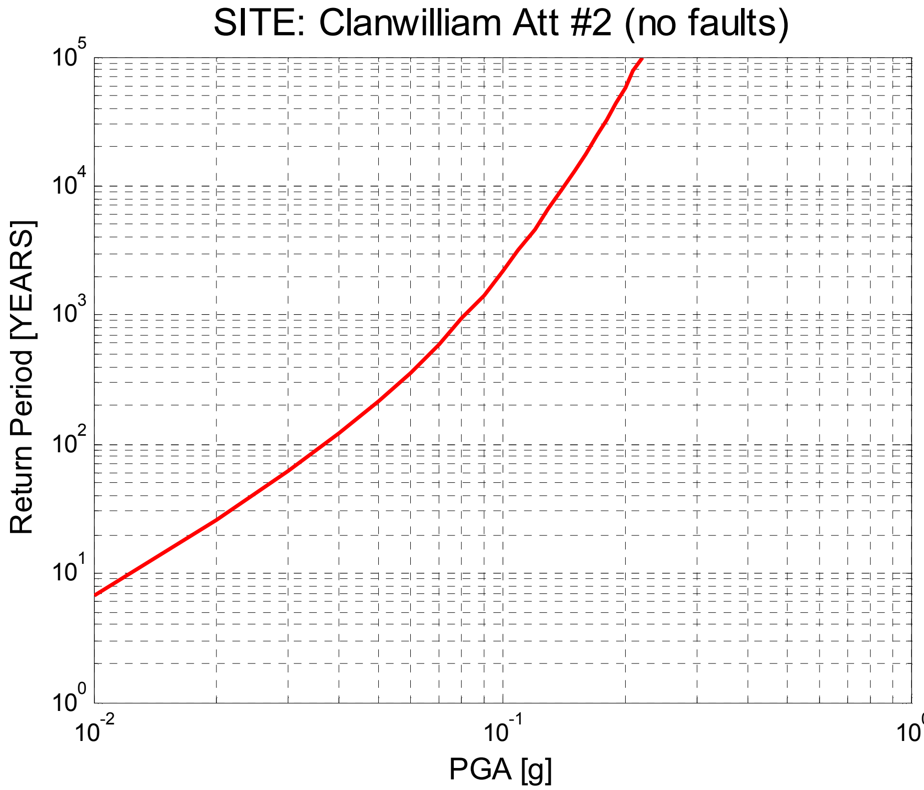

Figure 9.2(c) Mean return period of median value of horizontal PGA at the site of the dam, calculated for ground motion prediction equation by Spudich *et al.* (1999), (GMPE-2). Scenario #1: four known faults in vicinity of the dam are not active.

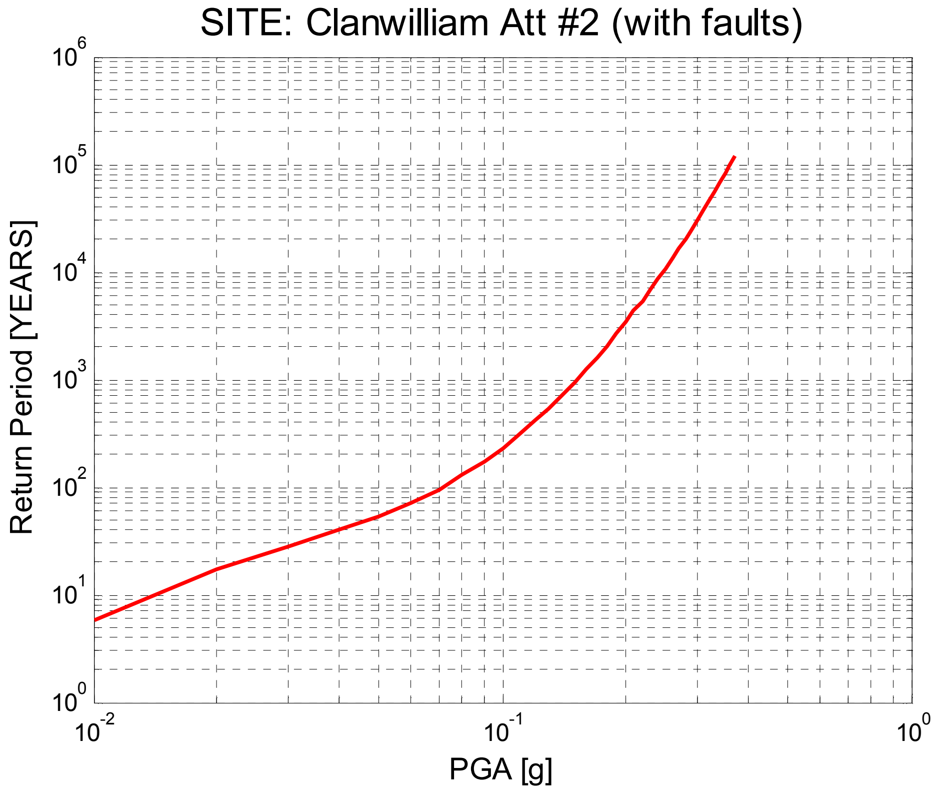

Figure 9.2(d) Mean return period of median value of horizontal PGA at the site of the dam, calculated for ground motion prediction equation by Spudich *et al.* (1999), (GMPE-2). Scenario #2: four known faults in vicinity of the dam are active.

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.

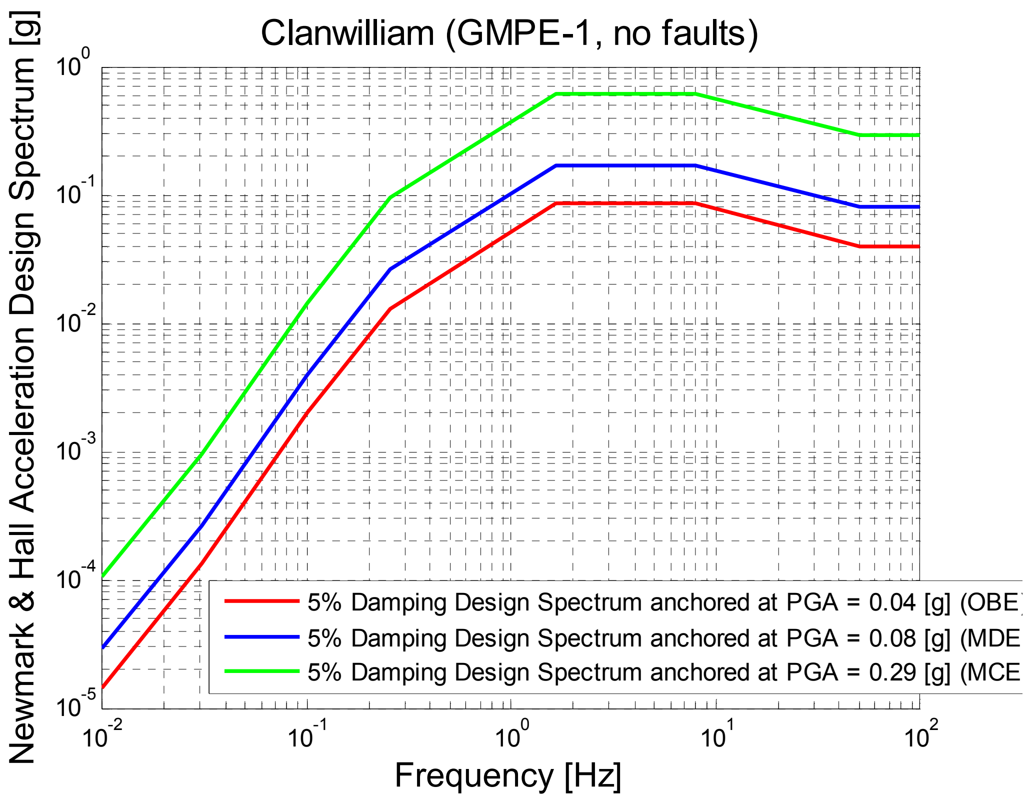

Figure 9.3(a). Newmark-Hall elastic design spectra anchored at the OBE, MDE and MCE values of horizontal PGA, calculated for ground motion prediction equation by Atkinson and Boore (2006), (GMPE-1). Scenario #1: four known faults in vicinity of the dam are not active.

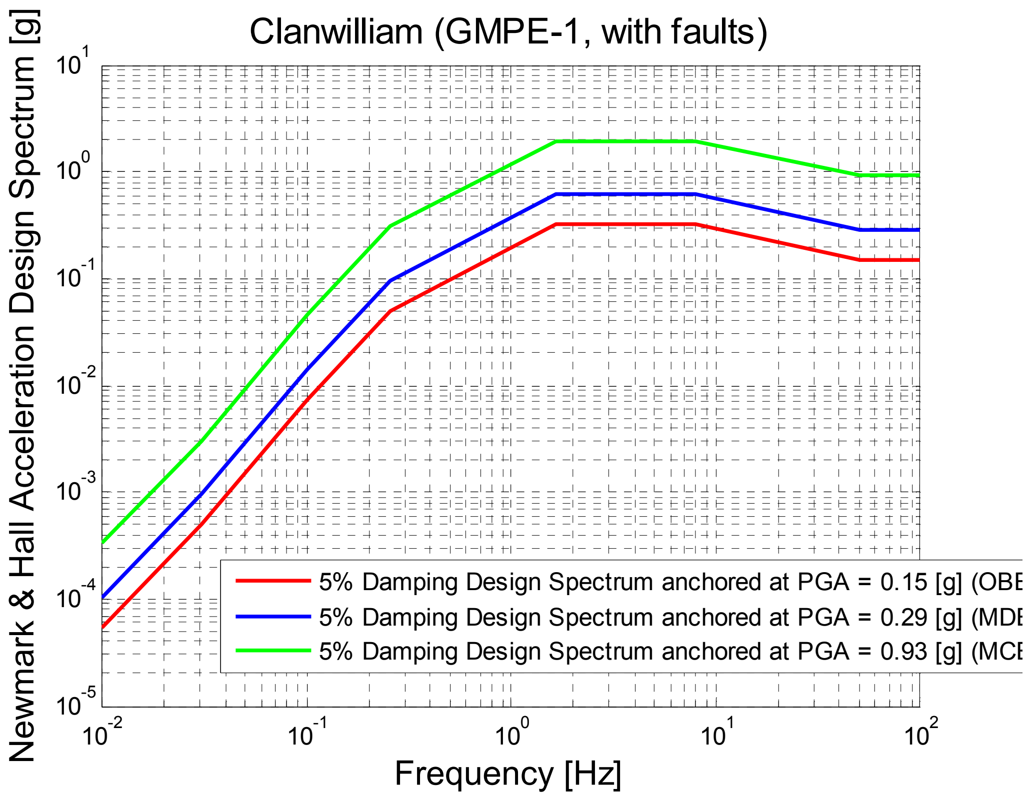

Figure 9.3(b). Newmark-Hall elastic design spectra anchored at the OBE, MDE and MCE values of horizontal PGA calculated for ground motion prediction equation by Atkinson and Boore (2006), (GMPE-1). Scenario #2: four known faults in vicinity of the dam are active.

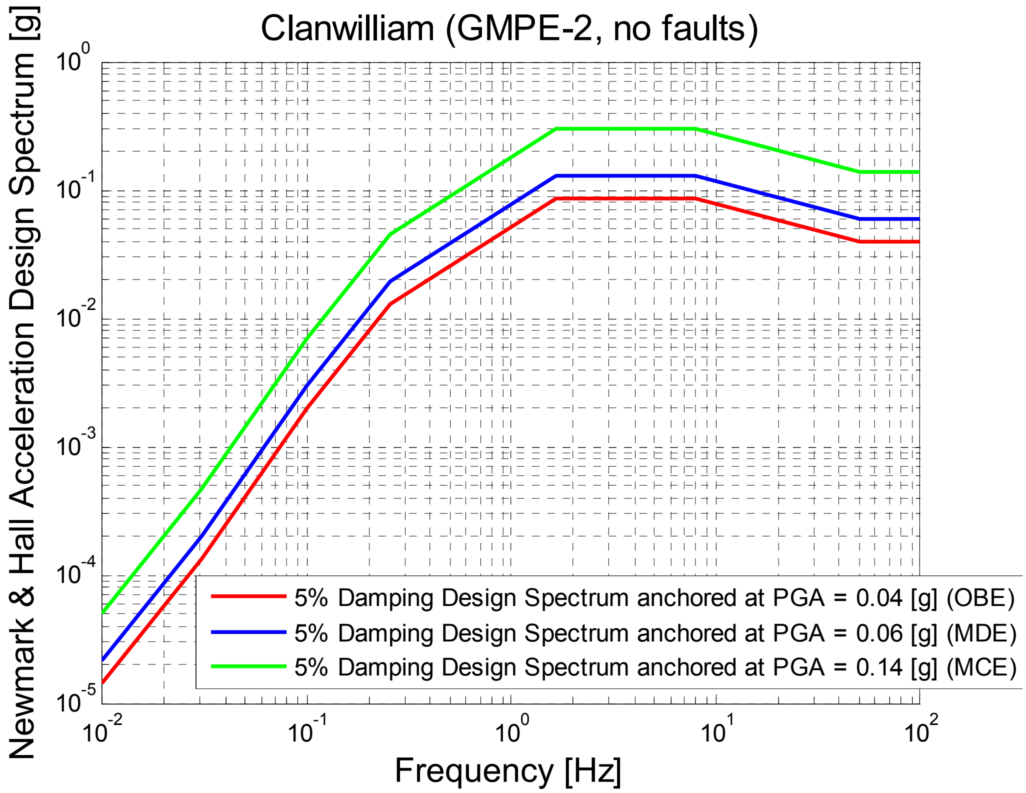

Figure 9.3(c). Newmark-Hall elastic design spectra anchored at the OBE, MDE and MCE values of horizontal PGA calculated for ground motion prediction equation by Spudich *et al.* (1999), (GMPE-2). Scenario #1: four known faults in vicinity of the dam are not active.

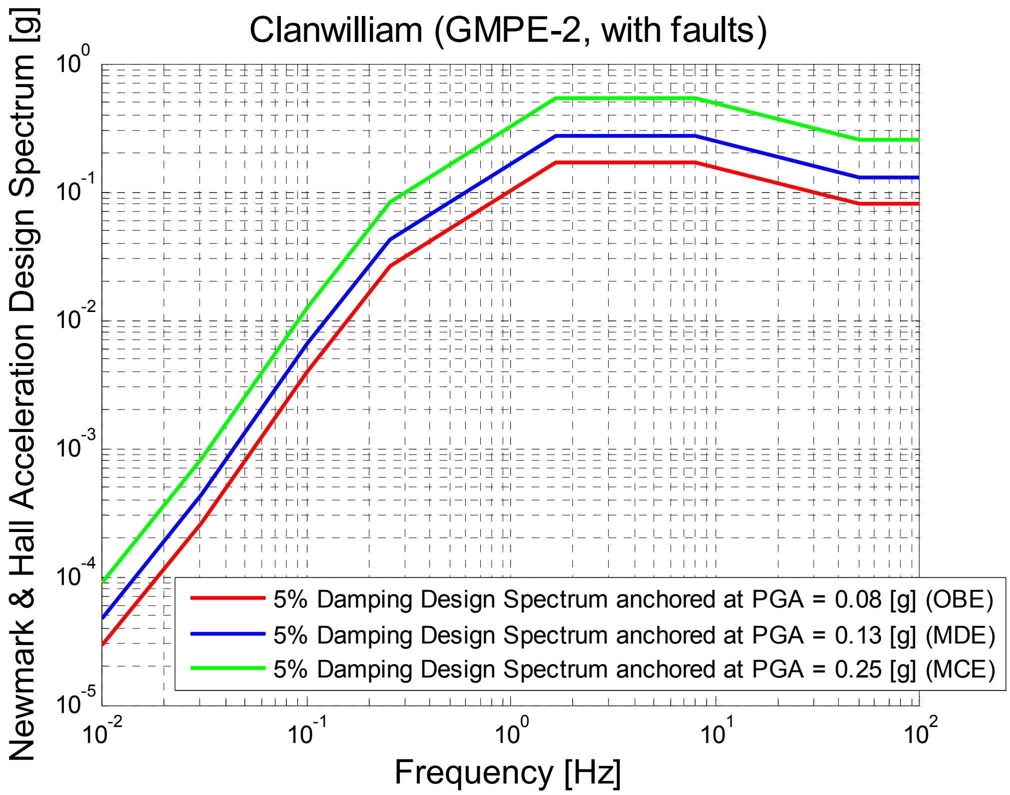

Figure 9.3(d). Newmark-Hall elastic design spectra anchored at the OBE, MDE and MCE values of horizontal PGA calculated for ground motion prediction equation by Spudich *et al.* (1999), (GMPE-2). Scenario #2: four known faults in vicinity of the dam are active.

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.

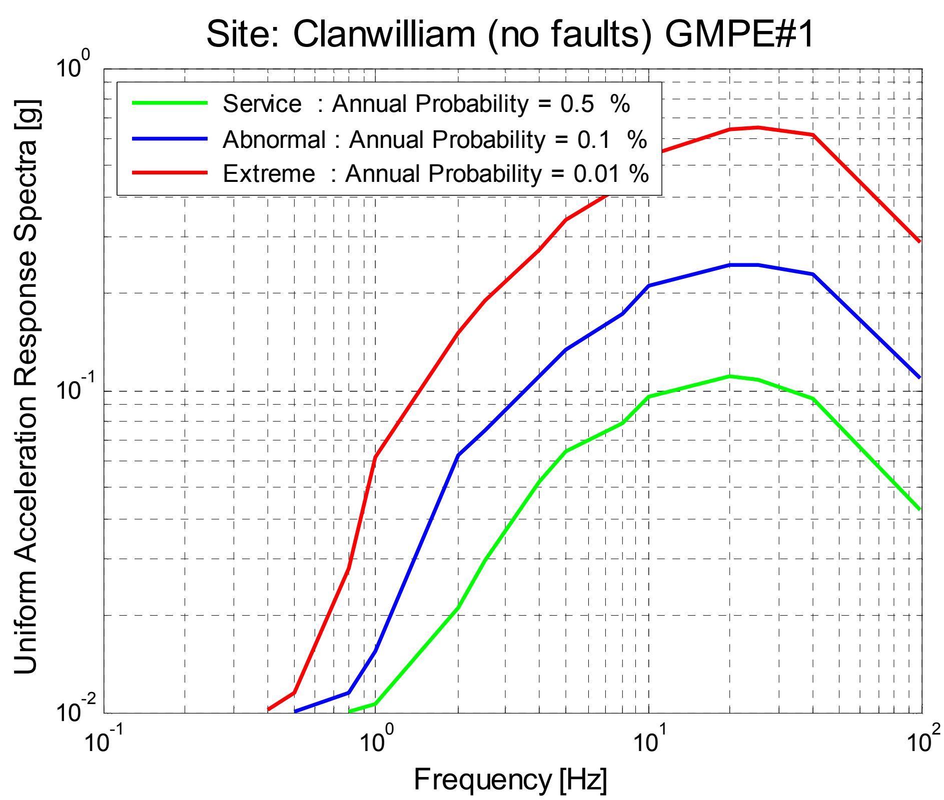

Figure 9.4(a). Horizontal Uniform Acceleration Response Spectra in terms of ground motion vibration frequency, calculated for GMPE by Atkinson and Boore (2006), (GMPE-1). Scenario #1: four known faults in vicinity of the dam are not active.

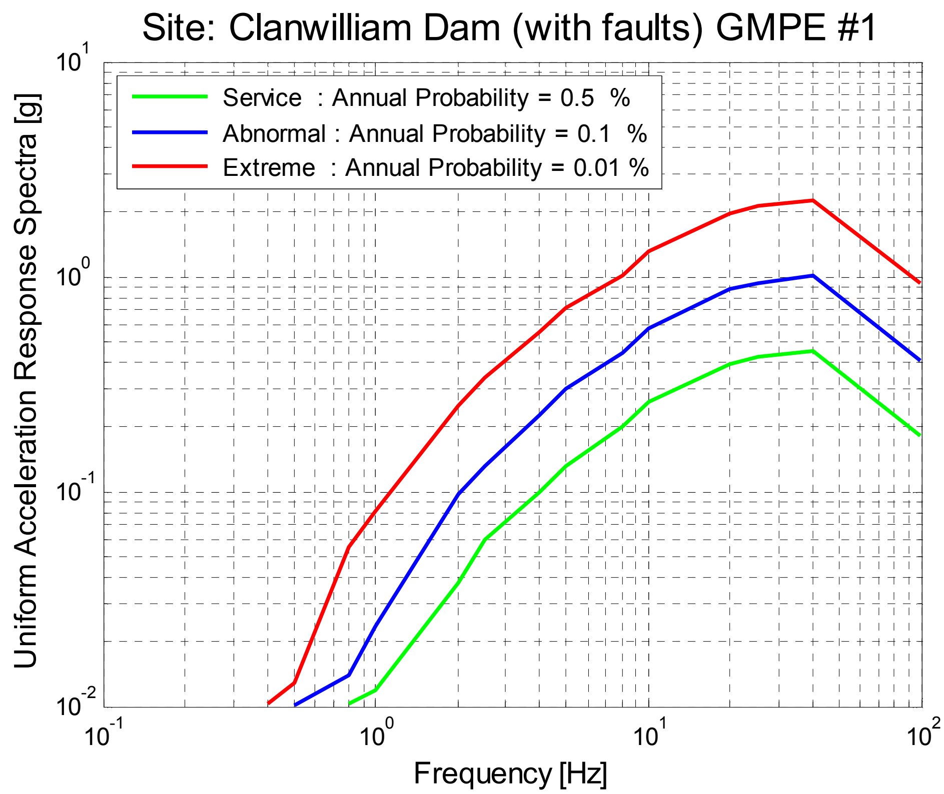

Figure 9.4(b). Horizontal Uniform Acceleration Response Spectra in terms of ground motion vibration frequency, calculated for GMPE by Atkinson and Boore (2006), (GMPE-1). Scenario #2: four known faults in vicinity of the dam are active.

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.

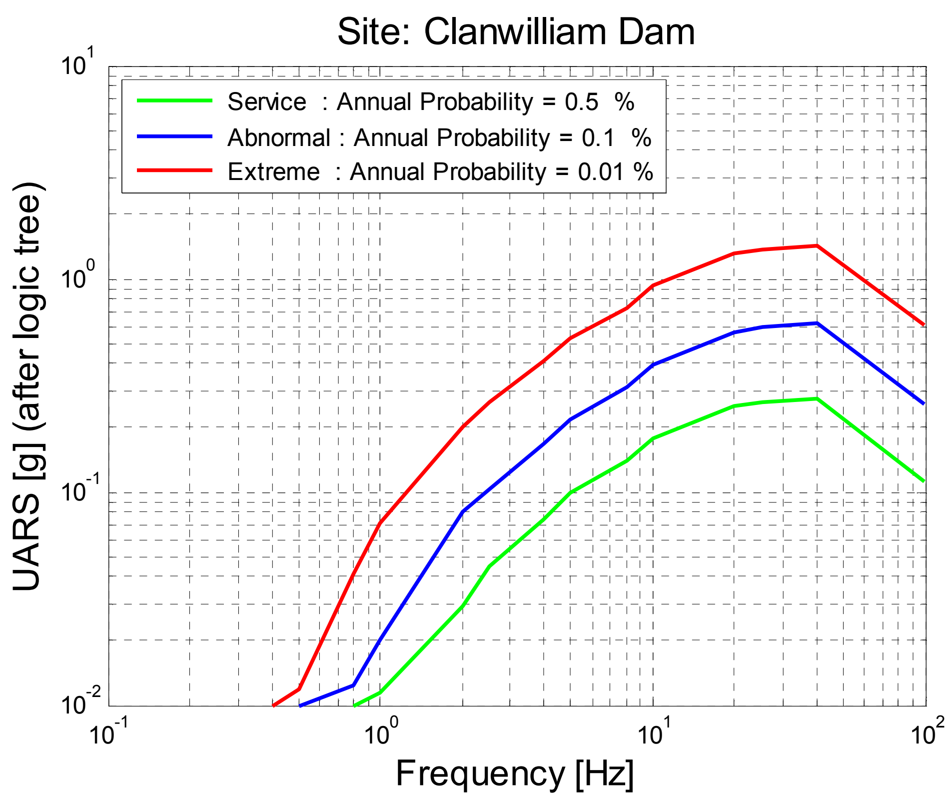

Figure 9.4 (c) Effect of application of logic tree formalism to the uniform horizontal ground motion acceleration spectra shown in Figure 9.4 (a)-(b). It was assumed that probabilities that faults are active (scenario #2) and not active (scenario #1) are the same and equal to 0,5.

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.

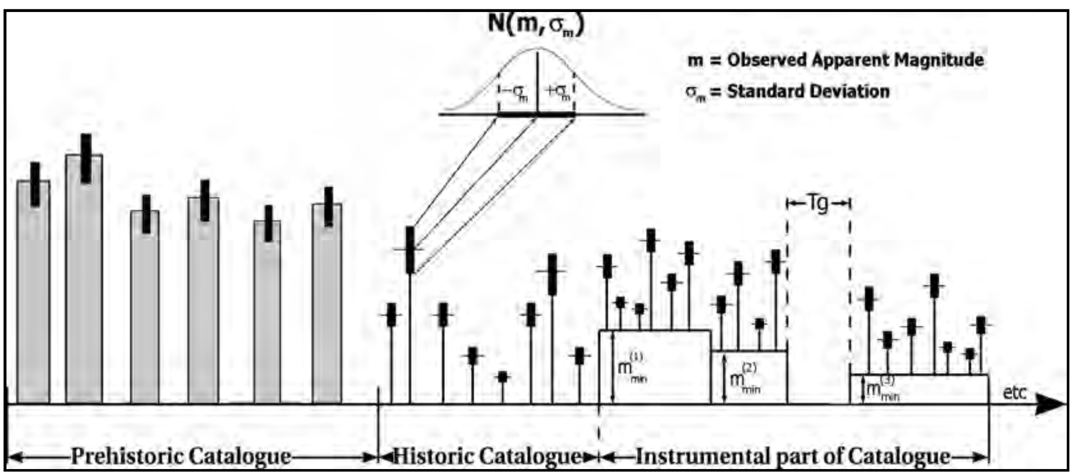

Figure 2.1 Illustration of data which can be used to obtain reccurence parameters for the specified seismic source. The approach permits the combination of the largest earthquakes (prehistoric/paleo- and historic) data and complete (instrumental) data having variable threshold magnitudes. It accepts '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 $p_\lambda = \bar{\lambda} / \sigma_\lambda^2$, $q_\lambda = \bar{\lambda}^2 / \sigma_\lambda^2$ and $\Gamma(\cdot)$ is the Gamma function (3). Parameter $\bar{\lambda}$ 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

$$F_M\left(m|m_{\min}\right) = C_\beta\left[1-\left(\frac{p_\beta}{p_\beta + m - m_{\min}}\right)^{q_\beta}\right], \tag{10}$$

where $p_\beta = \bar{\beta} / \sigma_\beta^2$ and $q_\beta = \bar{\beta}^2 / \sigma_\beta^2$. The symbol $\bar{\beta}$ 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 $q_\lambda = \bar{\lambda} \cdot p_\lambda$ and $q_\beta = \bar{\beta} \cdot p_\beta$, equations (9) and (10) may alternatively be written respectively as

$$P\left(n|t\right) = \frac{\Gamma\left(n+q_\lambda\right)}{n!\Gamma\left(q_\lambda\right)}\left(\frac{q_\lambda}{\bar{\lambda}_A t + q_\lambda}\right)^{q_\lambda}\left(\frac{\bar{\lambda}_A t}{\bar{\lambda}_A t + q_\lambda}\right)^n, \tag{12}$$

and

$$F_M\left(m|m_{\min}\right) = C_\beta\left[1-\left(\frac{q_\beta}{q_\beta + \beta\left(m - m_{\min}\right)}\right)^{q_\beta}\right], \tag{13}$$

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)

$$F_M^{\max}(m \mid m_0, t) = \sum_{i=0}^{\infty} P(i|t)\left[F_M(m \mid m_0)\right]^i, \tag{15}$$

Relation (15) can be expressed in a much more simpler form (e.g. Campbell, 1982), which may be written as

$$F_M^{\max}\left(m \middle| m_0, t\right) = \left[\frac{q_\lambda}{q_\lambda + \bar{\lambda}_0\, t\left[1 - F_M\left(m \middle| m_0\right)\right]}\right]^{q_\lambda}, \tag{16}$$

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

$$f_M^{\max}(m \mid m_0, t) = \frac{\bar{\lambda}_0\, t q_\lambda f_M(m \mid m_0) F_M^{\max}(m \mid m_0, t)}{q_\lambda + \bar{\lambda}_0\, t[1 - F_M(m \mid m_0)]}, \tag{17}$$

$\bar{\lambda}_0$ represents the mean of the distribution of the mean activity rate for earthquakes with magnitudes not less than m_0, and is given by

$$\bar{\lambda}_0 = \bar{\lambda}_A\left[1 - F_M\left(m \middle| m_0\right)\right], \tag{18}$$

where $\bar{\lambda}_A$, as defined above, is the mean of the distribution of the mean activity rate corresponding to magnitude value $m_{\min}$. $f_M\left(m \middle| m_0\right)$ is the PDF of earthquake magnitude. Based on (13) and the definition of the probability density function, it takes the following form:

$$f_M(m) = C_\beta\, \bar{\beta}\left(\frac{q_\beta}{q_\beta + \bar{\beta}(m - m_0)}\right)^{q_\beta + 1}, \tag{19}$$

After introducing the PDF (17) of the largest earthquake magnitude m within a period t, the likelihood function of unknown parameters $\boldsymbol{\theta}$ becomes:

$$L_0\left(\boldsymbol{\theta} \mid \boldsymbol{m}_0, \boldsymbol{t}_0, \boldsymbol{cov}\right) = \prod_{i=1}^{n_0} f_M^{\max}\left(m_{0i} \mid m_0, t_i\right), \tag{20}$$

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 $L_i\left(\boldsymbol{\theta} \middle| \boldsymbol{m}_i\right)$ 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 $L_i\left(\boldsymbol{\theta} \middle| \boldsymbol{m}_i\right)$ is the product of two functions, $L_i\left(\bar{\lambda} \middle| \mathbf{m}_i\right)$ and $L_i\left(\bar{\beta} \middle| \boldsymbol{m}_i\right)$.

The assumption that the number of earthquakes per unit time is distributed according to (12) means that $L_i\left(\bar{\lambda} \middle| \mathbf{m}_i\right)$ has the following form:

$$L_i\left(\bar{\lambda} \middle| \mathbf{m}_i\right) = const \cdot \left(\bar{\lambda}^{(i)} t + q_\lambda\right)^{-q_\lambda} \left(\frac{\bar{\lambda}^{(i)} t}{\bar{\lambda}^{(i)} t + q_\lambda}\right)^{n_i}, \tag{21}$$

where *const* does not depend on $\overline{\lambda}$ and $\overline{\lambda}^{(i)}$ is the mean activity rate corresponding to the threshold magnitude $m_{\min}^{(i)}$ and is given by,

$$\overline{\lambda}^{i} = \overline{\lambda}\left[1 - F_M\left(m_{\min}^{(i)} \mid m_{\min}\right)\right], \tag{22}$$

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

$$L_i(\overline{\beta}|\boldsymbol{m}_i) = \left[C_\beta\,\overline{\beta}\right]^{n_i} \prod_{j=1}^{n_i}\left[1 + \frac{\overline{\beta}}{q_\beta}\left(m_{ij} - m_{\min}^{(i)}\right)\right]^{-(q_\beta+1)}, \tag{23}$$

Relations (21) and (23) define the likelihood function of the unknown parameters $\boldsymbol{\theta}$ = ($\overline{\lambda}_A$, $\overline{\beta}$) 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 $\boldsymbol{\theta}$ = ($\overline{\lambda}$, $\overline{\beta}$), 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 $\frac{\partial \ell}{\partial \overline{\lambda}_A} = 0$ and $\frac{\partial \ell}{\partial \overline{\beta}} = 0$, where $\ell = \ln[L(\boldsymbol{\theta})]$.

A variance-covariance matrix $D(\boldsymbol{\theta})$, of the estimated hazard parameters, $\hat{\overline{\lambda}}$ and $\hat{\overline{\beta}}$, is calculated according to the formula (Edwards, 1972):

$$D(\theta) = -\begin{bmatrix} \frac{\partial^2 \ell}{\partial \overline{\lambda}^2} & \frac{\partial^2 \ell}{\partial \overline{\lambda}\, \partial \overline{\beta}} \\ \frac{\partial^2 \ell}{\partial \overline{\beta} \partial \overline{\lambda}} & \frac{\partial^2 \ell}{\partial \overline{\beta}^2} \end{bmatrix}^{-1}, \tag{24}$$

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] =

$$1 - \exp\left[-\sum_{i=1}^{n_s} \lambda_i \int_{m_{\min}}^{m_{\max}} \int_{R|M} \Pr[A \geq a \mid M, R] \, f_M(m) \, f_{R|M}(r \mid m) \, dr \, dm \right]. \qquad (28)$$

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

-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:

FAULT #1

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

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:
   ------------------------------------------

       - 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.


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 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 (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]
```

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

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

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
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 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 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:

    "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.
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                  : 21 JUN 2008 by A.K.
                  : 15 SEP 2009 by A.K.
                  : 28 OCT 2010 by A.K.

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===========================================================================

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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

$$log_{10} a_v(g) = -1.15 + 0.245M - 1.096 log_{10}(r + e^{0.256M}) + 0.096F - 0.0011Er,$$

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

$$log_{10} a_H(g) = -0.62 + 0.177M - 0.982 log_{10}(r + e^{0.284M}) + 0.132F - 0.0008Er,$$

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.

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