- *Site Investigations*
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Geotechnical Investigation for the proposed FGD Plant, Kusile Power Station, Mpumalanga: Revised Final Report

Client: GIBB

Reference: 17-0718R04

Dated: 14 December 2017

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Geotechnical Investigation for the proposed FGD Plant, Kusile Power Station, Mpumalanga: Revised Final Report

Reference: 17-0718R04 **Date: 14 December 2017**

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LEGAL NOTICE

Geotechnical Investigation for the proposed FGD Plant, Kusile Power Station, Mpumalanga: Final Revised Report

Reference: 17-0718R04 **Date: 14 December 2017**

EXECUTIVE SUMMARY

This report presents the results of a geotechnical investigation for the proposed Kusile FGD at Kusile in Mpumalanga, and presents the conclusions and recommendations for proposed excavations, foundations and earthworks. This final revised report includes pertinent recommendations for the foundation of the actual structure, details of which were only supplied after the completion of the investigation and the completion of the final report version R03 dated 9 December 2017.

Two rotary-cored boreholes were drilled to a maximum depth of just over 11 m depth. This was supplemented by the excavation of three test pits by TLB to between 2 and 3 m and four DPSH penetrometers to refusal at between 2.7 m and 7.2 m. ERT geophysical traverses were used mainly to pick up services prior to intrusive investigations.

The most important consideration in relation to the proposed development is the presence of hard competent dolerite bedrock at about 6 m depth and the excavation and earthworks implications thereof. The site is underlain by compacted fill, and further underlain by relatively unconsolidated fill to between 2 and 4 m depth. From between 2 and 4 m, residuum or soft shale and/or tillite bedrock was encountered, and from about 6.5 to 7.5 m, hard competent dolerite bedrock was encountered.

Soft excavation in terms of ***SABS 1200 D*** *may be anticipated to depths of between 2 and 4 m, and intermediate to hard excavation below these depths into the underlying weathered shale and/or tillite to a depth of about 7.5 m. Hard excavation to blasting is anticipated beneath this depth, if need be.*

Piled foundations have been proposed by Eskom for the portal frame structure and providing bearing pressures do not exceed 500 kPa, the competent dolerite bedrock at around 6.5 to 7 m depth will provide an adequate founding medium for end-bearing piled (CIA preferred) foundations for the facility. The upper fill layers may provide a bearing capacity of at least 250 kPa and therefore consideration should be given to a RC raft which could support both the portal frame structure and the floor which will support the 28m3 bins weighing 30t.

Finally, the ground conditions described in this report refer specifically to those encountered at the test positions advanced on site. It is therefore possible that conditions at variance with those discussed above may be encountered elsewhere on the site. In this regard it is critical that material management be maintained continuously on site and that ***GCS Geotechnical*** *carry out periodic inspections of the site during construction to ensure that any variation in the anticipated ground conditions can be assessed and revised recommendations subsequently provided in order to avoid unnecessary delays and expense. Furthermore it is important that the construction phase of the project be treated as an augmentation of the geotechnical investigation.*

Geotechnical Investigation for the proposed FGD Plant, Kusile Power Station, Mpumalanga: Final Revised Report

Reference: 17-0718R04 **Date: 14 December 2017**

Commercial:

GCS Geotechnical	GCS Geotechnical (Pty.) Ltd.

Technical:

CH	Chainage (metres)
mbgl	metres below ground level
masl	metres above sea level
NGL	Natural Ground Level
FL	Foundation Level
BH	Borehole
SPT	Standard Penetration Test
N	SPT N value (blows per 300 mm)
TLB	Tractor-mounted Loader Backhoe
TP	Test Pit
DCP	Dynamic Cone Penetrometer
EABC	Estimated Allowable Bearing Capacity
G1-G10	Standard classification of natural road building materials (TRH 14)
CBR	California Bearing Ratio
MDD	Maximum Dry Density (kg/m3)
MADD	Modified AASHTO Dry Density
OMC	Optimum moisture Content (%)
PI	Plasticity Index
LL	Liquid Limit
LS	Linear Shrinkage
RMR	Rock Mass Rating
GSI	Geological Strength Index
mi	Hoek-Brown Constant (origin & texture dependent)
RQD	Rock Quality Designation (%)
FF	Fracture frequency
UCS	Unconfined Compressive Strength (MPa)
C (c’)	Cohesion (kPa) – total stress and (effective stress)
Φ (Φ’)	Friction Angle (degrees) – total stress and (effective stress)
Kv	Modulus of Subgrade Reaction (MN/mm or kPa/mm)
CFA	Continuous Flight Auger (pile type)
DCI	Driven Cast In situ (pile type)
Cv	Coefficient of Consolidation (m2/yr)
Mv	Modulus of Compressibility (m2/MN)
MC1	Moisture Content Before Test (%)
MC2	Moisture Content After Test (%)
ρ	Dry Density (kg/m3)
VSR	Very soft rock
SR	Soft rock
MHR	Medium hard rock
HR	Hard rock
VHR	Very hard rock

Geotechnical Investigation for the proposed FGD Plant, Kusile Power Station, Mpumalanga: Final Revised Report

Reference: 17-0718R04 **Date: 14 December 2017**

1. INTRODUCTION & TERMS OF REFERENCE

At the request of Mr. Richard Myburgh of GIBB projects (hereafter referred to as GIBB), ***GCS Geotechnical*** (hereafter referred to as GCS) was asked to provide a proposal and cost estimate quotation for the undertaking of the geotechnical investigation for the proposed Kusile FGD, Kusile Power Station, Mpumalanga, which was sent through on 27 July 2017. The appointment was accepted and finalized on 27 September 2017. Fieldwork was conducted between 11 October and 2 November 2017.

A number of reports were provided culminating in R03 dated 9 December 2017. However, subsequent to the submission of this final revision, details of the actual structure were provided as follows:

- Portal frame structure supporting the double-volume, steel-clad structure.
- Concrete hardstand floor supporting twenty 28m3 bins for temporary storage of 30t each.
- Concrete approach and exit ramps.

2. AVAILABLE INFORMATION

The following information was drawn upon for the purposes of the investigation:

- The 1:250 000 Geological Map titled *"2528 Pretoria*" as compiled by the South African Geological Survey, 1978, and
- SABS 1200 D – Earthworks
- Eskom plan and elevation drawings dated June 2017.
- Pile and pile cap details.

The table below shows the available published physiographical information on the site.

Table 2-1: Summary of Available Desk Study Information

Parameter	Value	Reference
Development	Kusile FGD	GIBB & Eskom
Site coordinates	25°55'3.65"S / 28°54'39.03"E	GIBB & Eskom
Weinerts N-value	2-5	Weinert (1974)
Climatic Region	Moderate	TRH 2 (1978)
Rainfall	650-700	2526 Johannesburg (1999) 1:500 000 scale
Temperature	2-26˚ C	after DWAF (1986)
Evaporation	1700 mm	After DWAF (1986)
Water Balance	Deficit	Schulze (1985)
Weathering Type	Moderate decomposition with frost action and slight disintegration	Fookes et al (1971)
Geology	Shale and tillite of the Dwyka Formation underlain by dolerite	2528 Pretoria (1978) 1:250 000 scale
Soil Cover	-	Brink (1985)
Origin	-	Brink (1985)
Topography	<1:100	Garmap SA Topo & Rec 2012.1
Drainage	Not well defined	Garmap SA Topo & Rec 2012.1
Drainage Region	Quaternary Catchment: B20F	DWAF (1999)
Hydrogeology	Intergranular & fractured; 0.1-0.5l	2722 Kimberley (2003) 1:500 000 scale
Groundwater depth	Unknown	DWAF-WRC (1995)
Erodibility Index	16-20 (Low)	WRC (1992)
Seismic Intensity	VI (MMS)	Fernandez et al (1972)
Liquefaction	Unlikely (<50 cm/s2)	Welland (2002)

3. SITE DESCRIPTION

The site is located at Kusile Power Station at the following GPS coordinates:

- 25°55'3.65"S / 28°54'39.03"E

The total site area is approximately 0.25 Ha and according to historical Google Earth imagery the site may be underlain by a bulk fill platform.

The site is gently descending to the northwest, with an estimated gradient shallower than 1:50.

The general area functions as a container storage yard with a small workshop, many of the containers being used as offices. The remainder of the site is utilized as a parking lot for vehicles.

No vegetation was observed on site.

In terms of services on site, only a single subsurface electric cable was detected using a Cable Avoidance Tool (CAT) Scanner, and runs in an approximate southeast to northwest orientation from a power box north-eastwards across and off of the site.

4. GEOLOGY

Based on the 1:250 000 Geological Map titled *"2428 Pretoria*" (1978), the site is thought to be directly underlain by shale and tillite of the Dwyka Formation, Karoo Supergroup. However it was noted that the site was covered by a relatively thick fill horizon, underlain by residual and soft rock tillite with shale lenses, and finally underlain by weathered dolerite further underlain by medium hard rock to hard rock dolerite of the Karoo Supergroup

5. FIELDWORK

The fieldwork for this project was undertaken in stages in, beginning with the geophysics survey, and followed by test pitting and finally followed by rotary core drilling and dynamic probe super heavy (DPSH) testing.

5.1 Geophysical Survey

The main function of the geophysics was to prove subsurface services on site for the positioning of tests for the latter part of the investigation.

5.2 Test Pitting

Test pitting was undertaken in order to better understand the general shallow engineering properties of the site and also for the purpose of sample collection and analysis, all of which will aid in design.

Table 5.2: Summary of Shallow Soil Profile

Depth		Description	EABC (kPa)	Kv (kPa/mm)	E (MPa)	C (kPa)
From (m)	To (m)					
Compacted Fill						
0	0.4	Dry orange to yellow brown and red mottled white MEDIUM DENSE silty fine **SAND** with gravels	100-150	40-55	15-25	-
Fill						
0.4	3+	Dry to slightly moist orange to red brown LOOSE to MEDIUM DENSE silty fine to medium **SAND** with cobbles and gravels of shale	200-300+	85-100	10-25	-

EABC = estimated allowable bearing capacity (ignoring collapse potential)
Kv = modulus of subgrade reaction
E = elastic modulus

5.3 DPSH Penetrometers

DPSH testing was undertaken in order to quantify the soil strength parameters on site.

Table 5.3: Summary of DPSH Results

DPSH No	Depth (m-m)	SPT N	Consistency	EABC (kPa)	Kv (kPa/mm)	Other data
1	0-4.5 4.5-5.4	20-38 64-100	MD to D VSR	200-400 500+	65-100+	BH01
2	0-3.0 3.0-6.5 6.5-7.2	14-22 21-38 49-100	MD V Stiff VSR	150-200 200-350 500+	55-70 70-100	TP1&2
3	0-2.5 2.5-2.7	32-80 57-100	MD to D Refusal	300+ Boulder?	80-100	BH02
4	0-1.5 1.5-1.8 1.8-5.7 5.7-6.3	23-44 13 31-57 61-100	MD to D MD V Stiff VSR	200-400 150 300-500 500+	65-100+ 55 100+	TP2&3

The estimation of the modulus of subgrade reaction (Kv) will assist in the pile design and also the floor slab/RC raft design.

5.4 Core Drilling

Two rotary-core boreholes were drilled in order to determine the intermediate to deep ground conditions on site and to observe competent rock head level and deeper water levels, which will ultimately provide valuable information in terms of the earthworks and excavation requirements, according to SANS 1200:D.

Both boreholes showed a very similar profile with fill to 1.8 m and either fill or residuum to very soft to soft rock tillite to about 7 m below surface. Both boreholes intersected medium hard to hard rock dolerite at 7 m below surface.

Standpipe piezometers were installed and water rest levels were recorded at dolerite bedrock at 7 m below surface. The following shows a summary of the borehole logs:

Table 5.4: Summary of Borehole Logs

Depth (m-m)	Description	SPT N Value	Comments
BH1			
0-1.8	Fill	-	Gravely silty CLAY
1.8-6.25	VSR tillite	25	RQD = 0-10%
6.25-6.85	Residual dolerite	13R	Stiff sandy SILT
6.85-11.31	HR dolerite	-	RQD = 13-64%
BH2			
0-1.7	Fill	26R	Clayey gravely SILT
1.7-6.4	Fill or residual tillite	13	VSR tillite boulder 2.83-3.45m
6.4-6.97	Residual dolerite	10R	Firm SILT
6.97-11.47	MHR to HR dolerite		RQD = 60-100%

Groundwater levels were recorded 24 hrs after drilling at between 7m and 8.3 m below surface.

6. GROUNDWATER

No groundwater seepage occurred on site in any of the test pits, although during summer months and during times of prolonged or heavy rainfall, perched groundwater may be present at relatively shallow depths on site.

The borehole drilling showed the groundwater rest level at between 7 m and 8.3 m below surface, coincident with the underlying dolerite bedrock level.

7. LABORATORY TESTING

Laboratory tests were scheduled on four soil samples recovered from the site.

The following tests have been carried out:

- Foundation indicator tests (PSD, hydrometer and Atterberg Limits),
- Quick shear box tests, and
- Chemistry tests (pH and EC).

The detailed laboratory test results are given in Appendix B, while summaries of these results are presented below in Tables 7a to 7e.

Table 7a: Summary of Foundation Indicators

TP No.	Depth (m-m)	LL	PI	GM	CBR* (%)	Classifications		
						TRH14	PRA	USCS
Fill								
1	0-3	32	10	1.8	31	G7-G8	A.2.4	SC
2	1.7-3	29	9	1.77	33	G6-G8	A.2.4	SC
3	0-1.2	28	10	1.69	30	G7-G8	A.6	SC
3	1.2-1.9	24	8	1.49	29	G6-G8	A.2.4	SC

*CBR estimated from PI-GM relationship.

Table 7b: Summary of Compaction Test Result

TP	Depth (m-m)	MDD (kg/m3)	OMC (%)	Swell (%)	CBR (%)				
					90	93	95	98	100
Fill									
1	0-3	2012	11.9	0.96	2	3	4	6	9
2	1.7-3	2153	9.8	1.07	4	6	8	13	17

MDD = maximum dry density
OMC = optimum moisture content

Table 7c: Shearbox Test Results

TP No.	Depth (m)	Average Initial MC (%)	Average Final MC (%)	Approximate Initial Dry Density (kg/m3)	Results	
					Friction Angle (°)	Cohesion (kPa)
Fill						
1	1.7-3	8.3	8.9	2063	17	80

Table 7d: Summary of Corrosivity Tests

TP	Depth (m-m)	pH	EC (mS/m)	Resistivity (Ohm/cm)	Degree of Corrosivity
Fill					
1	0-3	9.6	166	6024	Not generally corrosive
2	1.7-3	9.5	171	5848	Mildly corrosive
3	0-1.2	9.0	129	7752	Not generally corrosive
3	1.2-1.9	9.3	167	5988	Mildly corrosive

Table 7e: Materials Classification and Recommended Usage

Material Description	Classification	Recommended Usage
Fill	PI = 8-10 GM = 1.49-1.8 Classification: A.2.4 – A.6; SC; Low PE; Inferred G8	Materials qualify as G8 (low grade fill).

The laboratory test results show that the upper 3 m of material to be excavated is a fairly good quality material (G5 to G6) based on the grading and foundation indicators. **However, the limited compaction test results show that the material is downgraded to G8/G10 and this is probably due to the breakdown of the shale gravel component. Therefore, this fill can only be re-used in possible compacted soil mattress construction if more conclusive laboratory testing prove otherwise.**

8. DEVELOPMENT RECOMMENDATIONS

8.1 Materials Usage

The site soils includes variable fill horizons, ranging from silty gravelly sands underlain by sandy silts with gravel and cobbles, and further underlain in part by weathered shale or tillite bedrock.

Based on visual and tactile means, coupled with laboratory results, the materials qualify as possible G6-G7 (lower subbase to upper selected layers) quality but due to the low CBR values under compaction (probably due to breakdown of the shale gravel) is downgraded to a G8-G10 quality material.

8.2 Soil Movement

Laboratory results suggests that the silty gravelly sandy fill qualifies as low potential expansiveness, which equates to little or no surficial movement, according to Van der Merwe & Savage (1979).

Collapse settlement may be of concern within the upper fill layers and consolidation settlement within the clayey residuum.

8.3 Foundation Loads to be Accommodated

Eskom have provided the following information on the structure and loads:

- Steel portal frame structure.
- Concrete floor 34.2mx30m to support 20No x 28m3 containers weighing 30 tons each. This is combined equivalent to 6 000 kN.
- Therefore bearing pressure below slab is between 5 and 10 kPa.
- Maximum combined SLS and ULS compression loads of portal frame is 130+175 = 305 kN. For 1x1m pad footing bearing pressure will be 305 kPa.
- Maximum tension loads of similar value.
- Approach and exit ramps for delivery trucks.

8.4 Allowable Bearing Capacity

The upper fill layers are of inherently good granular quality (G6-G7) but appears to breakdown under compaction to G8-G10 and may require over-excavation and replacement by more suitable G7 quality material compacted in controlled layers

Based on the laboratory and in situ test results, the following bearing capacity estimation can be made of the upper granular fill:

C = 80 kPa
Phi = 17 degrees
Ɣd = 2.1 kN/m3

NƔ= 3
Nq = 5
Nc =15

Qf = (0.4x2.1x1x3) + (1.3x80x15) + (2.1x1x5) = 1573 kPa

The estimated allowable bearing capacity of a 1x1m pad foundation is therefore about 500 kPa. **This would suggest that pad foundations are definitely an option to be considered to support the portal frame structure.**

An allowable bearing capacity in excess of 500 kPa may also be adopted in fresh dolerite bedrock beneath the shale/tillite, which was observed at around 6.5 to 7 m depth. The variation in bearing capacity with depth is provided in Tables 5.1a and 5.1b.

8.5 Foundation Options

Piled foundations have been adopted by Eskom for the steel portal frame structure and if this option is chosen, then end-bearing CIA piles to about 7 m would be sufficient. However, a number of other options should be considered.

The upper fill levels to about 3 m have been described as medium dense and the DPSH results show 20 to 30 blows per 300 mm in the upper fill horizon to 3 m depth. This translates to a SPT N value of 26 to 39 and this suggests an allowable bearing capacity of at least 250 kPa. Therefore, the following foundation options for the main structure should be considered:

8.5.1 Main Structure

Option A:

- Piling of the individual portal frame columns with end-bearing CIA piles to about 7 m and socketed into the dolerite bedrock to resist the uplift forces of wind.
- Over-excavation of upper 1 m of shale fill and replace with G7 quality material compacted in controlled 150 mm layers compacted to 95% MADD to support nominally-reinforced 200 mm thick jointed concrete slab. The earthworks should be done prior to the piling.

Option B:

- Over-excavation of the upper 1 m or so of the shale fill and replace with G7 quality material compacted in controlled 150 mm layers compacted to 95% MADD.
- Pad foundations for portal frame columns.
- Nominally-reinforced 200 mm thick concrete floor cast separate from the columns.

Option C:

- Reinforced concrete raft to provide solid floor and monolithically-cast plinths to support portal frame columns.

8.5.2 Approach Ramps

Unfortunately, the type of structure with approach and exit ramps was not made known before the investigation and thus only empirical interpretations and recommendations can be made for the ramps as follows:

- The shallow subgrade comprises medium dense silty sand (SC) with a CBR of between 4 and 8% at 95% MADD.
- The compacted fill layer to 0.5 m depth is of G6-G7 quality and classifies as A.2.4.
- The in situ material can therefore be used as a selected layer beneath the layerworks to support the concrete slab and truck loads.

8.6 Excavatability & Earthworks

Soft excavation in terms of **SABS 1200 D** may be anticipated to depths of between 2 and 4 m, with intermediate to hard excavation likely occurring below these depths into the underlying weathered shale and/or tillite to a depth of about 7 m. Hard excavation to blasting is anticipated beneath this depth, if need be.

8.7 Drainage

For the promotion of a stable site, it is extremely important that adequate drainage, both surface and subsurface, be designed and constructed so that no water ingress into the subsurface rock fractures in and around the foundation base is possible. Drainage should be such that any rainfall is diverted to the nearest stormwater drainage system. Areas of potential pooling or damming of rainfall on site should be carefully designed and sloped so as the remove this water from the site. Once the excavation has been opened, it is recommended that it be rapidly blinded with mass concrete as soon as possible, so as to prevent any rainfall occurring having an impact on the founding surface. Having said this, the exposed dolerite surface will unlikely weather rapidly, and should remain relatively stable and intact, providing it is not highly fractured.

9. CONCLUSIONS & RECOMMENDATIONS

General

- This report presents the results of a geotechnical investigation for the proposed Kusile FGD storage warehouse at Kusile in Mpumalanga, and presents the conclusions and recommendations for proposed excavations, foundations and earthworks.

- The most important consideration in relation to the proposed development is the presence of good quality granular fill to 3 m, residual tillite to 7 m and hard competent dolerite bedrock at about 7 m depth and the excavation and earthworks implications thereof.

Geology & Ground Conditions

- The site is underlain by compacted fill, and further underlain by relatively unconsolidated fill to between 2 and 4 m depth. From between 2 and 4 m, soft shale and/or tillite bedrock is encountered, and from about 6.5 to 7.5 m, hard competent dolerite bedrock is encountered.

Excavatability

- Soft excavation in terms of **SABS 1200 D** may be anticipated to depths of between 2 and 4 m, and intermediate to hard excavation below these depths into the underlying weathered shale and/or tillite to a depth of about 7.5 m. Hard excavation to blasting is anticipated beneath this depth, if need be.

- ***Foundations & Allowable Bearing Capacity***

  Piled foundation have apparently been chosen by Eskom and this can certainly be considered as one of the options. Conventional pad foundations, thick concrete slabs and even a RC raft should also be considered and entered into a cost matrix.

- An allowable bearing capacity of 500 kPa may be adopted in fresh dolerite bedrock beneath the shale/tillite, which was observed at around 6.5 to 7 m depth for end-bearing piles. The upper fill layers can accommodate at least 250 kPa but may require compaction to ensure continuity.

Further Investigations

- Finally, the ground conditions described in this report refer specifically to those encountered at the test positions advanced on site. It is therefore possible that conditions at variance with those discussed above may be encountered elsewhere on the site. In this regard it is critical that material management be maintained continuously on site and that ***GCS Geotechnical*** carry out periodic inspections of the site during construction to ensure that any variation in the anticipated ground conditions can be assessed and revised recommendations subsequently provided in order to avoid unnecessary delays and expense. Furthermore it is important that the construction phase of the project be treated as an augmentation of the geotechnical investigation.

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Appendix A
Test Pit Profiles

Appendix B
Rotary-Core Borehole Profiles

Appendix C
DPSH Test Results

Appendix D
Geophysics Report

Appendix E
Laboratory Test Results

Figure 1
Site Plan

Figure 2
Geological Plan