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GAMSBERG TSF

GAMSBERG DESIGN AND ENGINEERING OF THE TSF FOR PHASE 2 GEOTECHNICAL INVESTIGATION

GEOTECHNICAL INVESTIGATION FINAL INTERPRETIVE REPORT

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ABBREVIATIONS

BH .... Borehole
ERT .... Electric Resistivity Tomography
GPS .... Global Positioning System
Ha .... hectare
Km .... kilometer
KP .... Knight Piésold
PGA .... Peak Horizontal Ground Acceleration
MASW .... Multichannel Analysis of Surface Waves
m .... meter
masl .... Meter Above Sea Level
Mtpa .... Mega Ton Per Annum
RWD .... Return Water Dam
SRF .... Seismic Refraction
TSF .... Tailings Storage Facility
TP .... Test pit
Vs .... Shear-Wave Velocity
WGS .... World Geodetic System

1. INTRODUCTION

Knight Piésold (KP) was appointed by Vedanta Resources (Contract number: GB20223271) to carry out a geotechnical investigation for the proposed extension of the current Gamsberg Phase 1 Tailings Storage Facility (TSF) and Return Water Dam (RWD) as part of Phase 2 of the Gamsberg Project at Gamsberg Mine, in the Northern Cape Province. The geotechnical investigation is part of the Design and Engineering of the TSF for Phase 2 of the project to increase the ore beneficiation capacity with an additional 4 Mtpa.

This investigation was carried out to provide an understanding of geotechnical conditions at the proposed TSF and RWD sites for design purposes. This includes the nature and extent of the underlying soils and rock, provide foundation recommendations and comment on the reuse of material for construction purposes.

This report documents the results of the investigation which includes the desktop study, surface geophysical survey, test pitting and rotary core drilling. This final interpretative report includes all site investigation data and the laboratory results. The evaluation of the geotechnical conditions and subsequent recommendations take all the geotechnical data into account, including the latest laboratory test results, which were not available when the preliminary report was compiled.

2. AVAILABLE INFORMATION

KP conducted a geotechnical investigation in April 2017 as part of the Detailed Design and Construction Quality Supervision of the TSF Phase 1. Refer to report: Gamsberg Mine, New Tailings Storage Facility Geotechnical Investigation (Phase 1) Final Report, Knight Piésold, Report No. 2374 (2017) [1] [1].

The Phase 1 investigation comprised the excavation of thirty-three test pits (designated P1 to P33) and two boreholes (designated BH1 and BH2). The test pits were excavated to refusal depth of a 20-Ton excavator and logged in situ by a registered engineering geologist according to standard practice. The test pit results are summarized in Table 1 and the typical profile was recorded as follows:

- Aeolian silty sand covers the site to a maximum depth of 0.4 m.
- Calcrete horizons at various stages of development and cementation occur within the residual soils below the surface aeolian soil layer. Nodular calcrete and honeycomb calcrete occur to a maximum depth of 2.5 m.
- Hardpan calcrete occurs as a very dense very strongly cemented sandy gravel layer where excavator refusal conditions were met.
- Hardpan ferricrete occurs within the TSF extension area as very dense very strongly cemented sandy gravel to a maximum depth of 2.3 m.
- Below the pedogenic soils, very soft rock gneiss, retrieved as silty sandy gravel, occurs from an average depth of 0.8 m.
- Excavator refusal occurred at depths of between 1.0 m and 3.1 m, in all test pits, where pedocretes were not present or where they were poorly developed and could be excavated through.
- No ground water seepage was observed in any of the test pits.

[1] References are indicated thus and are listed at the back of the report.

3. SCOPE OF WORKS

The scope of work for the detailed design level geotechnical investigation was set out in KP's proposal (reference: 301- 00541/21 Rev02) [2].

The investigation comprised a desk study of available information and site walk over to note any salient features. A geophysical investigation was carried out to provide additional information regarding the depth to bedrock and variation within the soil and rock profile.

The geotechnical assessment investigated the subsurface conditions through excavation of test pits along the TSF wall alignment and within the RWD footprint, using a 20-Ton excavator. Rotary core boreholes were allowed to investigate ground conditions at the proposed decant tower and to investigate geotechnical conditions at depth, in areas of adverse geotechnical conditions, if found.

The design programme had been modified by the design team prior to the commencement of the investigation to change the previously envisaged penstock to a floating structure, thus no decant tower is planned or required geotechnical investigation.

In addition to the geotechnical conditions on site, the characterization and determination of the critical state line (assuming 1 type of fine tailings) and determination of interface shear strength between the tailings, clay geosynthetic liner and geomembrane was required.

Laboratory testing was carried out in accordance with the geotechnical conditions encountered on site.

This report serves as an interpretive report to present the site investigation results, as well as subsequent evaluation of the geotechnical conditions, conclusions, and recommendations.

4. SITE DESCRIPTION

Gamsberg Mine is located in the Namakwa District of the Northern Cape Province. The mine occurs approximately 11 km east of Aggeneys town and approximately 45 km west of Pofadder town, south of the N14 national road. Refer to the Site Locality Plan shown in Figure 1.

The investigation is conducted on the TSF facility north of the Gamsberg mine and N14 road. Two areas of investigation are detailed in this report, namely the Phase 2 TSF site that is approximately 130 ha in size, directly north of the existing Phase 1 TSF, and the new RWD, approximately 5 ha in extent south-west of the existing TSF and west of the existing RWD.

The sites are undeveloped with minor borrow activities in the TSF footprint area. They comprise arid short, scattered shrubs and limited grass cover.

The co-ordinates of the central point of the TSF and RWD sites are 29°10'55.59"S 18°56'49.34"E and 29°12'5.38"S 18°56'33.20"E, respectively.

The site topography is relatively flat, sloping gently downwards from the north to south, from 960masl to 948 masl.

A seasonal river drains the area in a southerly direction, approximately 2.8 km west from the TSF site with visible sheet wash features draining towards the river.

No ground water seepage was observed during the investigation, and a few rock sub-outcrops were encountered during excavation of test pits.

5. GEOLOGY AND SOIL

5.1 REGIONAL GEOLOGY

The mine lies on the Bushmanland Group and Gladkop Metamorphic Suite of the Mokolian age. The Bushmanland group is structurally complex with a poly-metamorphosed geology, it predominantly comprises sedimentary and volcanic rocks of the Khurisberg, Aggeneys and Kamiesberg Subgroups. The rocks of the area have been intensely foliated with a highly variable orientation, dipping between 10˚ and 80˚ in various directions. Refer to Figure 2 for an excerpt of the regional geology map.

These rocks are overlain by Quaternary deposits comprising sand, scree, rubble and sandy soils. From aerial imagery, the rock contacts between rock types are not clearly defined.

5.2 SITE GEOLOGY

According to the published 1:250 000 scale Geological series map sheet 2918 Pofadder [3], the sites are underlain by calc-silicate gneiss, schist, amphibolite and minor lenticular quartzite belonging to the Wortel Formation, Aggeneys Subgroup and leucogneiss belonging to the Koeipoort Gneiss, Gladkop Metamorphic Suite.

The Quaternary sand deposit covers the majority of the sites and occurs as a thin surface layer. Observation of aerial imagery of the site indicates several approximately east-west striking lineaments. The transported and in situ residual soilsinclude variable degree of pedogenic deposits as described in Section 8.1 below.

5.3 CLIMATE AND WEATHERING

Climate determines the mode of weathering and rate of weathering. The effect of climate on the weathering process (i.e. soil formation) is determined by the climatic N-value defined by Weinert. The climatic N-value is greater than 30 for this site, which indicates mechanical disintegration is the dominant mode of weathering with no secondary minerals development [4]. This typically results in thin residual soil profiles of coarse gravel developed from the disintegrating rock.

Residual soils in these climatic environments often undergo various degrees of pedogenic cementation, such as calcification. Calcrete is a pedogenic soil that is produced by the cementation of calcium carbonate ($CaCO_3$). Various development stages of calcrete can occur, depending on the degree of cementation. These deposits are often erratically deposited leading to variable ground conditions over short distances. Furthermore, these cemented horizons may lead to excavation difficulties.

6. SEISMICITY

South Africa is located on the African Tectonic Plate which, in comparison to other tectonic plates, is fairly stable with low degrees of movement. Much of the African Plate, except the East African Rift Zone, is considered to be a zone of low tectonic activity. This does not suggest that no seismic activity occurs but rather that the probability of some is much lower. Seismic hazard is represented by the peak horizontal ground acceleration (PGA) of any particular area: the greater the PGA the greater the probability of seismic activity.

The image below provides the indicative seismic risk across Southern Africa and the corresponding peak ground accelerations with a 10% probability of exceedance within a 50-year period. The PGA on site is indicated to be approximately 0.08g which equates to a “V” Degree classification on the Modified Mercalli Scale.

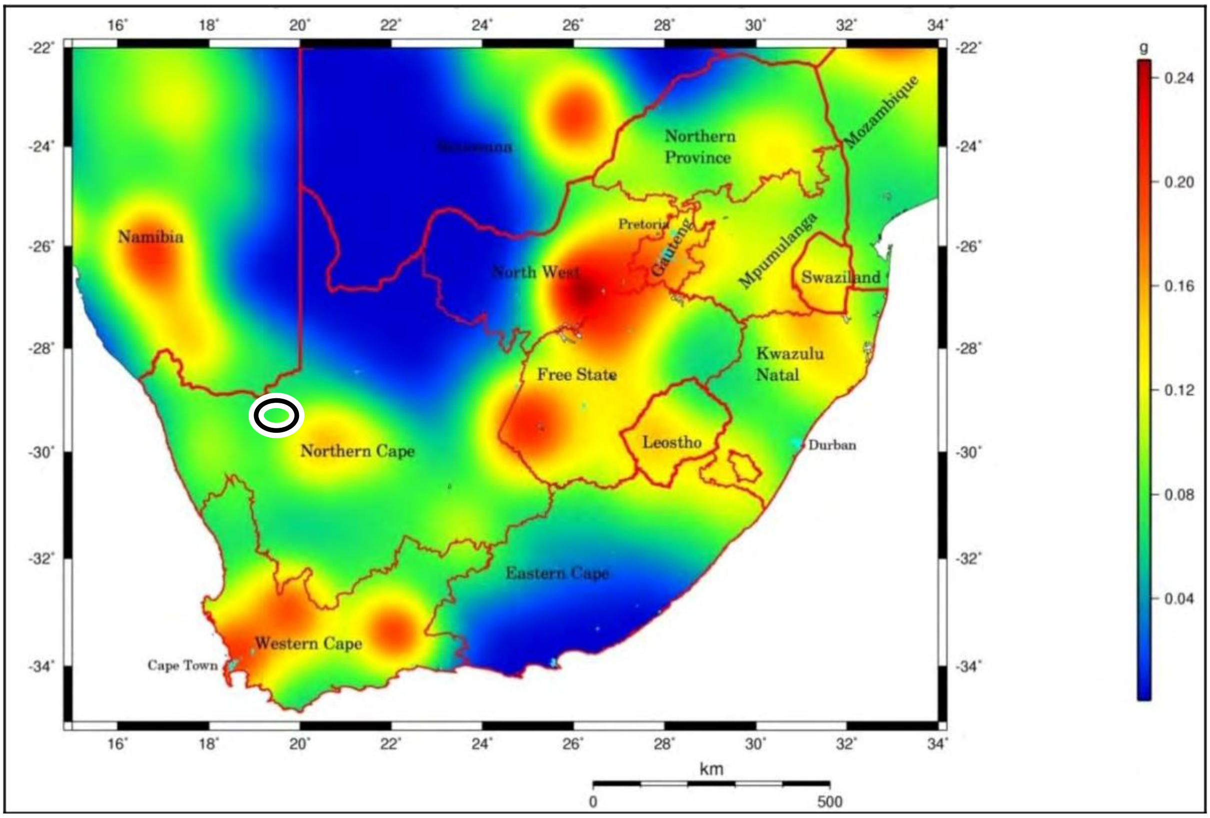

Image 1: Seismicity Map of South Africa

In addition to the regional seismic data, a site-specific study was carried out for the Gamsberg Zinc Mine as documented in Knight Piésold’s Memorandum Letter reference RI21-00398 dated 11 November 2022. The pertinent information from that document is included below:

- The mine site is located in a region of low seismicity, typical of an intra-plate region, characterised by generally low levels of seismic activity. Higher seismicity zones such as the Witwatersrand Basin and the Ceres Cluster are more than 500 km away from the mine site.

- The most significant source for potential earthquakes within 200km radius of the Gamsberg Zinc Mine site is the Pofadder Shear Zone, a NW-trending shear zone approximately 500km long located ~35km northeast of the site in southern Namibia and northwestern South Africa.
- Higher seismicity zones such as the Witwatersrand Basin and the Ceres Cluster are more than 400 km away from the mine site.
- Earthquake ground motion parameters (PGA and spectral accelerations) have been provided for site conditions with V_{s30} values of 760 m/sec and 360 m/sec (corresponding to very dense soil or soft rock). Seismic coefficients are provided for simplified (screening level) seismic stability analyses for the TSF, and have been calculated for a range of AEP values (1:475 to 1:10,000) for foundation conditions represented by V_{s30} values of 760 m/sec and 360 m/sec.
- The PGA obtained for the Gamsberg project site probabilistic seismic hazard analysis for the return period of 475 years, 2,475 years, and 10,000 years are 0.02g, 0.05g, and 0.12g for the site based on a V_{s30} value of 760m/s, while a PGA of 0.03g, 0.07g, and 0.15g were obtained for the same period with a shear wave velocity of 360m/s. A 50% to 25% increase (amplification) in PGA is observed for a V_{s30} decrease from 760m/s to 360m/s.
- For an annual exceedance probability of 1:10,000 the TSF, the horizontal seismic coefficient is 0.06 and 0.075 (50% of the PGA of 0.12g and 0.15 g) for V_{s30} values of 760 m/sec and 360 m/sec respectively.
- It is recommended that a dynamic site response analysis is undertaken to determine the amplification of ground motions as seismic waves propagate through the foundation soils and the TSF. Measuring the site seismic waves propagation can be done using either surface-wave survey, refraction survey, down-hole survey, and cross-hole survey.

7. METHOD OF INVESTIGATION

7.1 GEOPHYSICAL SURVEY

The geophysical survey was conducted by GeoFocus (Pty) Ltd in November 2022 as part of this investigation, and comprised two perpendicular traverses, one orientated in north-south direction and the other in an east-west direction. The traverses were conducted on the TSF site and the orientations were selected to intersect anticipated lineament orientations perpendicularly, to provide the best resolution of these structures, if present. Three different geophysical methods were undertaken across each traverse, namely:

- 3 500m of Electric Resistivity Tomography (ERT): to indicate resistivity variations within the soil/ rock profile, which often represent variations in geotechnical conditions, geological structures like faults and intrusions as well as zones of weathering that can influence ground water flow dynamics.
- 3 040m of Seismic Refraction (SRF) to indicate variation in the seismic velocity of the soil/ rock profile, which is generally related to density and strength. A 10m geophone spacing was used to provide information to aid the delineation of bedrock depth.
- 3 090m of Multichannel Analysis of Surface waves (MASW) to indicate variation in shear wave velocity of the soil/ rock profile, which can be correlated to stiffness parameters. A 5m geophone spacing was used to provide stiffness parameters and an understanding of the soil/ rock behaviour under strain.

The geophysical data was used to position the test pits and boreholes to ensure areas of significant variation or detrimental geotechnical conditions were not overlooked. The geophysical data was also used to extrapolate the data from the point information (test pits and boreholes) across the site. The geophysical report is presented in Appendix A and is evaluated in conjunction with the other results below.

7.2 TEST PITS

The investigation of the shallow geotechnical conditions comprised test pits excavated from 30 November to 11 December 2022. The positions were selected to provide representative information along the TSF wall to supplement the existing basin information and within the RWD to provide information regarding the foundation conditions. The test pits were excavated using either a 320D or 330D excavator machine (provided by Fraser Alexander) to refusal condition, at a maximum depth of 3.9 m and 3.6 m at the TSF and RWD, respectively. A total of 41 test pits were excavated for the project of which 33 test pits (TP201 to TP233) were excavated at the TSF site and 8 test pits (RWDTP1 to RWDTP8) at the RWD.

The test pits were profiled and photographed in-situ by an engineering geologist according to current practice [5]. The TSF test pit profiles are summarised in Table 2 and RWD profiles summarised in Table 4, the soil profiles are presented in Appendix B.

The positions of the test pits were recorded using a hand-held GPS with an accuracy of approximately 3m. The coordinates of these positions are displayed on the test pit profiles in WGS84 datum and South African Grid (Lo19). Refer to Figure 4 for site plan showing the test pit positions at the TSF and Figure 5 showing the test pit positions at the RWD.

7.3 ROTARY CORE DRILLING

Two rotary core boreholes (TSFBH1 to TSFBH2) were drilled at the TSF site and one rotary core borehole (RWDBH3) was drilled at the RWD, by the drilling contractor Geomechanics, between the 3 and 12 December 2022. The boreholes were drilled into sound bedrock to depths ranging between 11.5m and 14.13m below surface level.

Standard Penetration Tests (SPTs) were carried out where suitable conditions were encountered, however refusal occurred with all SPTs attempted.

The core boxes were photographed and logged by a KP engineering geologist according to standard practice. The positions of the boreholes were recorded using a hand-held GPS with an accuracy of approximately 3m. The coordinates of these positions are displayed on the borehole logs in South African Grid (Lo19) format and WGS84 datum. The rotary core borehole profiles are summarised in Table 3, while the full profiles and core photographs are presented in Appendix C. Refer to Figure 4 for borehole positions for the TSF site and Figure 5 for test pit positions for the RWD site.

7.4 LABORATORY TESTING

Disturbed soil samples were collected from representative horizons at the TSF and RWD. The samples were submitted for testing at Specialised Testing Laboratory in Pretoria.

Representative disturbed tailings samples were also taken on the southern and western wall of the existing TSF on site. These samples were also tested at Specialised Testing Laboratory in Pretoria.

The laboratory results are summarised in Table 5 and Table 6 and the full results presented in Appendix D.

8. INVESTIGATION RESULTS

8.1 GEOPHYSICAL SURVEY

The geophysical survey undertaken comprised seismic refraction, MASW and electrical resistivity tomography. The results are discussed below.

Seismic surveys are generally aimed at mapping the depth to bedrock, and through correlation of the seismic velocities of the different layers encountered. These can be correlated with rock mass properties (e.g, load bearing capacity) with depth. MASW surveys provide shear-wave velocities (Vs), which can be corelated to stiffness parameters allowing for the modelling of strain. ERT is mostly aimed at mapping geological structures like faults and intrusions as well as zones of weathering that can influence ground water flow dynamics. ERT is also used to map the transition to hard rock where a change in resistivity provides sufficient resolution.

Two lines were surveyed perpendicular to each other over the centre of the TSF site where line 1 was surveyed in an east-west orientation and line 2 in a north-south orientation. The traverses were positioned to intersect anticipated lineament orientations perpendicularly, to provide the best resolution of these structures.

The geophysical report describes the presence of a loose surface soil overlying weathered rock at variable and shallow depths. The contact between the calcified surface soils and weathered bedrock is gradual and not distinct. It is anticipated that sound bedrock is found from 5m to 10m below surface. Notable subvertical joints/discontinuities are noted generally towards the ends of the surveyed sections as substantial, lateral, resistive heterogeneity within the bedrock, dominant along the E-W line 1 compared to N-S line 2, which may be indicative of a dominant N-S structural orientation and preferential weathering along linear features. A deeper weathered profile is indicated in the central portion of the site, at and south of the survey line intersection as shown clearly by the SRF N-S section (line 2 between 6770250 N and 6769975 N).

8.2 TYPICAL SOIL PROFILE

8.2.1 TAILINGS STORAGE FACILITY

The TSF comprises two typical profiles, the more common along the north and eastern sides of the site includes a thin colluvium layer (<0.3 m thick) overlying scattered calcrete and shallow very soft to soft rock gneiss from depths as shallow as 0.1 m in places. The common profile over the central and western parts of the TSF site comprises thin alluvium (<0.4 m thick) overlying gneiss bedrock from as shallow as 0.1 m in places.

In general, the TSF is underlain by shallow (from a depth of 0.4 m to 1.6 m) bedrock of varying rock type bands comprising gneiss, granite-gneiss, schist, amphibolite and quartzite. Excavator refusal was encountered between surface and depths of 3.9 m in all excavated test pits at the TSF.

Where present, along the northern perimeter of the existing TSF, the fill is typically less than 0.4 m thick overlying calcrete on the east and western border.

8.2.2 RETURN WATER DAM

The typical profile at the return water dam is that of calcrete and silcrete in varying proportions, indurating alluvial sand and gravel above the bedrock. The typical profile across this relatively small area is detailed below.

- 0-0.1 m Dry, orange brown, very loose to loose, silty fine to coarse sand, alluvium.
- 0.1-0.6 m Dry, white and orange, medium dense to dense, nodular, honeycomb and hardpan calcrete gravel, cobbles and boulders.
- 0.6-1.2 m Dry, white, loose to medium dense, intact silty sandy gravel, nodular calcrete. Calcrete often silicified as well but predominantly calcified.
- 1.2 m + Dry, orange brown, medium dense becomes very dense with depth, silty fine to coarse sand, silicified alluvium.
- 2.6-3.6 m Refusal in all TP's (except RWDTP5) in silicified alluvium. RWDTP5 refused on quartzite/ quartzite pegmatite.

8.3 LABORATORY TESTING

Laboratory testing was carried out on representative samples to define the material properties in the TSF and the RWD to provide information for the design.

Foundation indicators, Proctor compaction, California Bearing Ratio, remoulded shearbox, remoulded permeability, chemical dispersivity, double hydrometer, Basson Index and pH and electrical conductivity tests were performed on representative samples.

8.3.1 TSF GENERAL

The material tested at the TSF typically comprises alluvium (calcified or ferruginous) or soft rock gneiss with one fill sample being included. The colluvium encountered on site was limited to less than 0.3 m in thickness.

The fill found along the existing TSF northern perimeter comprises slightly plastic sandy gravel with a grading modulus (GM) of 2.14.

8.3.2 TSF ALLUVIUM

The alluvium comprises coarse, calcified and ferruginous alluvium to shallow depths of less than 0.7 m, it was retrieved as sandy gravel to gravelly sand, with a fines (silt and clay) percentage of less than 13% and plasticity index (PI) of less than 11%. The Unified Soil Classification system categorises the material as SC to SM. The pH is slightly basic at 7.9 and the electrical conductivity of 0.038 S/m indicates corrosive soils.

Standard Proctor compaction results indicate a maximum dry density (MDD) at proctor compaction of between 1934 kg/m^3 and 1956 kg/m^3 with an OMC of 10.7%. The California Bearing Ratio is 16% to 18%, at 93% Mod AASHTO density. The material classifies as a G7 quality material (COTO, 2020).

The calcified alluvium was tested for remoulded shear strength parameters and permeability. The shear box test conducted at 93% MDD of Standard Proctor Compaction revealed internal friction (φ) of 38° and cohesion (c) of 0 kPa. The coefficient of permeability is 1.38x10^{-8} m/s for the remoulded calcified alluvium. The ferruginised coarse alluvium revealed φ=36° and c=13 kPa. The cohesion is anticipated to be an apparent cohesion generated due to the particle interlock and should be cautiously used in calculations.

8.3.3 TSF SOFT ROCK GNEISS

The soft rock gneiss is excavated/ retrieved as a soil comprising slightly to non-plastic sandy gravel or gravelly sand with a fines percentage of less than 5% and a grading modulus (GM) of more than 2.11.

The pH is slightly basic at 8.3 and the electrical conductivity of 0.021 S/m indicates corrosive material.

Laboratory results indicate a maximum dry density (MDD) at standard Proctor compaction of approximately 2004 kg/m^3 with an OMC of 9.4%. The California Bearing Ratio is 28%, at 93% Mod AASHTO. The material classifies as a G6 quality material (COLTO, 1998).

The soft rock gneiss was also tested for remoulded shear strength parameters and permeability. The shear box test conducted at 93% MDD of Standard Proctor Compaction revealed remoulded friction (φ) of 41° and cohesion (c) of 0 kPa and permeability of 1.26x10^{-8} m/s.

8.3.4 RWD GENERAL

The site is generally underlain by alluvium silicified above the calcrete horizon overlying the gneiss bedrock at depth.

8.3.5 RWD ALLUVIUM

The alluvium includes silicified alluvium with a typical component of calcified soil within the shallow profile. The alluvium comprises sandy gravel to gravelly sand with a fines (silt and clay) percentage of less than 13% and plasticity index of less than 15%. The Unified Soil Classification system categorises the material as SC to SM. The pH is slightly basic at 8.3 and the electrical conductivity of 0.323 S/m which indicates very corrosive soils.

Laboratory results indicate a maximum dry density (MDD) at standard Proctor compaction between 1832 kg/m^3 to 1920 kg/m^3 with an OMC of 11.7% to 13.6%. The California Bearing Ratio is 13% to 19%, at 93% Mod AASHTO. The material classifies as a G7 to G8 quality material (COLTO, 1998).

The calcified alluvium was tested for remoulded shear strength parameters and was the same as for the RWD with remoulded friction (φ) of 38° and cohesion (c) of 0. The silicified alluvium tested weaker and more permeable than the calcified alluvium with remoulded friction (φ) of 36° and cohesion (c) of 0 kPa and coefficient of permeability 5.79x10^{-7} m/s

8.3.6 RWD PEDOCRETE

The pedocrete includes nodular calcrete and honeycombed with occasional calcrete boulders. The pedocrete comprises sandy gravel to gravelly sand with fines (silt and clay) percentage of less than 22% and plasticity index of less than 18%. The Unified Soil Classification system categorises the material as SC to GM-GC. The pH is slightly basic at 8 and the electrical conductivity of 0.191 S/m indicates very corrosive soils.

Laboratory results indicate a maximum dry density (MDD) at standard Proctor compaction of 1803 kg/m^3 with an OMC of 15%. The California Bearing Ratio is 15%, at 93% Mod AASHTO. The material classifies as a G7 quality material (COLTO, 1998).

The nodular calcrete was similar to the calcified alluvium when tested for remoulded shear strength parameters. The shear box test revealed 93% MDD of Standard Proctor Compaction remoulded friction (φ) of 38° and cohesion (c) of 0 kPa.

8.3.7 CHEMICAL TESTS

8.3.7.1 Dispersivity

Chemical dispersion and Double hydrometer tests were carried out to evaluate the soil based on the propensity of the material to erode pipes and gullies due to soil dispersivity. The material underlying the TSF is considered non-dispersive but the material underlying the proposed RWD is considered dispersive [6].

8.3.7.2 Aggressivity

The chemical test (Basson Index) was conducted on the soil samples from the site to determine the aggressiveness towards concrete and corrosivity toward steel [7]. The result indicates the following:

Basson Parameter	TP205/1	TP205/2	TP215/1	RWDTP3/3	RWDTP7/2	RWDTP7/3
Material type	**Calcified Alluvium**	**Soft rock Gneiss**	**Ferruginised coarse Alluvium**	**Calcified Alluvium**	**Nodular Calcrete**	**Silicified Alluvium**
pH of the sample (corrected at 20° C)	8.5	9.0	9.9	7.8	7.8	7.8
the Langelier Index for the sample	0.0	-0.1	-0.2	0.3	0.4	0.5
Ryznar Index for the sample	8.4	9.1	11.9	7.6	7.5	7.4
corrosivity ratio	6.7	2.8	4.8	262	248	307
Aggressiveness Index (Nc)	322	443	1799	-717	-855	-889
Aggressiveness	Aggressive	Aggressive	Aggressive	Aggressive	Aggressive	Aggressive
Corrosive (steel)	Aggressive	Aggressive	Aggressive	Aggressive	Aggressive	Aggressive
Overall aggressiveness towards concrete	Mild to Moderate	Mild to Moderate	Very High	None to mild	None to mild	None to mild

The table below provides an interpretation for the above results.

Index	Aggressive	Neutral	Non-Aggressive
Stability Ph, (Phs)	7 < pH	7 = pH	7 > pH
Langelier Index	Negative Value	Zero	Positive Value
Ryznar Index	>7.5	6 - 7	< 6
Corrosivity towards steel	>0.2		

The following table provides guidelines for assessing the overall Aggressiveness (N_c).

N_c	Aggressiveness
Less than 300	None to mild
400 – 700	Mild to Moderate
800 – 1000	High
= or > 1 100	Very High

The TSF soils vary from mild to very highly aggressive towards concrete and are corrosive towards steel.

The RWD soils are generally not aggressive to mildly aggressive toward concrete and corrosive towards steel.

9. GEOTECHNICAL EVALUATION

9.1 EXCAVATABILITY

The excavation characteristics of different soil horizons on site have been evaluated according to SANS 1200D [8] which details the standardised classification for earthworks excavations. The excavation class descriptions can be described as follows:

- "Soft Excavation": Excavation in material that can be efficiently removed by a back acting excavator of flywheel power approximately 0.10 kW per millimetre of tined-bucket width, without the use of pneumatic tools such as paving breakers.
- "Intermediate Excavation": Excavation in material that requires a back-acting excavator of flywheel power exceeding 0.10 kW per millimetre of tined-bucket width or the use of pneumatic tools before removal by equipment equivalent to that specified for soft excavation.
- "Hard Rock Excavation": Rock that will be very difficult to excavate with an excavator and may require blasting, splitting and/or the use of rock breaking equipment, typically from medium hard to hard rock.

The test pits on the TSF site were excavated using an excavator. Across the site, excavations predominantly classify as "soft excavation" to a typical depth of 0.4 m. However, "intermediate" conditions were observed to an average depth of 1.6 m below surface. Local variations have indicated bedrock and "intermediate" to "hard rock" excavation conditions are anticipated from a depth as shallow as 0.1 m but typically from between 0.1 m to 0.8 m in the north between TP219 and TP226. "Intermediate" to "hard rock" excavation is generally deeper than 1.5 m along the northern boundary of the existing TSF and from 2.0 m in the southern portion of the TSF extension area. The TSF basin is variable and "hard rock" conditions are found from 0.35 m to 2.7 m below surface.

9.2 REUSE OF MATERIALS

9.2.1 TSF

The alluvium at the TSF may be suitable for reuse as a G7 quality material, although this material is non-dispersive it is classified as aggressive towards concrete and corrosive towards steel. The material has a low PI (<11%) and may be reused. The alluvium when remoulded is capable of achieving φ-values of 38° and cohesion of 0 kPa. The permeability is in the order of 10^{-8} m/s.

The colluvium and calcrete is limited in distribution across the site and was thus not considered for bulk earthworks. It is anticipated that the calcrete may be suitable for reuse.

The soft rock gneiss is non-dispersive but aggressive towards concrete and corrosive towards steel. This material may be suitable for reuse as G6 quality material. The soft rock gneiss when remoulded is capable of achieving φ-values of 41° and cohesion of 0 kPa. The permeability is in the order of 10^{-8} m/s.

9.2.2 RWD

The alluvium at the RWD was found through laboratory testing to be similar but slightly weaker (CBR strength) than that at the TSF. Laboratory results of the alluvium at the RWD indicates dispersive soils and aggressivity towards concrete and corrosivity towards steel. This material may be considered for reuse as a G7 to G8 quality material but is not recommended for reuse below water bearing structures due to the dispersive nature of the material, alternatively if this material is required measures to neutralise the dispersivity can be considered by the design engineer. The alluvium when remoulded is capable of achieving φ-values between 36° and 38° and cohesion of 0 kPa. The permeability is in the order of 10^{-7} m/s.

The calcrete that was tested indicates high dispersivity, aggressivity towards concrete and corrosivity towards steel. This material may be considered for reuse as a G7 quality material but is not recommended for reuse below water bearing structures due to the highly dispersive nature of the material, alternatively if this material is required measures to neutralise the dispersivity can be considered by the design engineer. The calcrete when remoulded can achieve φ-values of 38° and cohesion of 0 kPa.

All materials used for construction purposes, should be overseen by a suitably experienced materials engineer, and should be tested regularly and consistently to confirm the materials are in accordance with the required specifications.

9.3 MATERIAL STRENGTH AND PERMEABILITY

The anticipated values for the various materials considered for re-use are provided based on published literature [9] [10] [11]:

Material	Cohesion (c') kPa	Friction (φ') °	Permeability (k) m/s
TSF Alluvium	0 - 5	31 - 36	10^{-6} to 10^{-7}
TSF Soft Rock Gneiss	0	32 - 37	10^{-5} to 10^{-7}
RWD Alluvium	0 - 5	30 - 34	10^{-6} to 10^{-7}
RWD Calcrete	0 - 5	31 - 36	10^{-5} to 10^{-7}

The samples selected for shearbox and permeability testing were taken from disturbed samples for indications of the reuse of materials. The results returned values that were in-line and slightly better than anticipated values from literature when remoulded to 93% of Maximum Dry Density (Standard Proctor Effort). This may be attributed to the good compaction effect achieved for the material.

Material	Cohesion (c') kPa	Friction (φ') °	Permeability (k) m/s
TSF Alluvium	0	36 - 38	10^{-8}
TSF Soft Rock Gneiss	0	41	10^{-8}
RWD Alluvium	0	36 - 38	10^{-7}
RWD Calcrete	0	36	Not tested

10. CONCLUSION AND RECOMMENDATIONS

Two areas have been investigated for the phase 2 TSF expansion at Gamsberg Zinc Mine. The proposed phase 2 TSF will be an expansion to the north of the existing TSF while the proposed RWD is south-west of the existing TSF. The investigations comprised geophysical surveys, test pit excavation, rotary core drilling and laboratory testing.

The soil profiles generally comprised pedogenic soils, and were underlain at shallow depth by weathered bedrock, with the exception of deeper soil profiles comprising pedogenic alluvial soils. A prominent quartzite and gneiss ridge is outcropping in the western, central portion of the proposed TSF area. Similar shallow hard rock features are anticipated across the site at shallow depth as encountered during the construction of the existing TSF.

The RWD is generally underlain by deep alluvial soils, becoming silicified with depth.

10.1 TSF

The TSF expansion area is underlain by alluvium, calcrete in varying stages of pedogenesis and shallow granite/gneiss bedrock. The soil in this area is generally thin with soft or medium hard rock varying from depths of 0.1m below surface to 0.7m. The transported, pedogenic and residual soils are considered suitable for reuse and should be removed or ripped and recompacted to remove loose pockets and prevent settlement of the thin soil profile. Soft excavation is typically anticipated to depths of at least 1.2m below ground level across the site but localised intermediate to hard excavation is anticipated, particularly where quartzite and shallow rock bands were observed (western central portion of the site).

Surface water and river channel water must be diverted to prevent seepage, ponding and excess water below the TSF.

Insitu permeability of the compacted excavation floors should be carried out to determine compliance with the design barrier system.

The following earthworks are proposed:

- Excavate and stockpile the upper 300 mm (organic content) at the TSF footprint for future (topsoil) remediation.
- Should deeper foundations be required according to the design, excavate or localised rip/blast and stockpile the material for reuse.
- The excavation floor must be ripped 200 mm deep and compacted to 95% Standard Proctor Maximum Dry Density (MDD) at Optimum Moisture Content (OMC) to densify the loose in-situ soil.
- Where subsurface drains are required, localised intermediate to hard excavation is anticipated across the majority of site.
- Provision should be made for a protective layer below the barrier system.

10.2 RWD

The RWD area is underlain by alluvium with shallow calcrete horizons becoming silicified with depth before granite/gneiss bedrock is encountered. The thick soil horizon is anticipated to have loose horizons or pockets as observed in the test pit profiles to at least 3.5m below surface. The transported and pedogenic soils are considered for reuse however, the soils are indicated to be dispersive and not suitable below water bearing structures.

Surface water and river channel water must be diverted to prevent seepage, ponding and excess water below the RWD.

Insitu permeability tests of the compacted excavation floors should be carried out to determine compliance with the design barrier system.

The following earthworks are proposed:

- Excavate and stockpile the upper 300 mm at the RWD footprint for future (topsoil) remediation.
- Found the RWD at least 3.5m below ground level.
- Excavate 300 mm below the proposed founding depth, insitu rip and recompact the excavation floor to 95% Standard Proctor Maximum Dry Density (MDD) at Optimum Moisture Content (OMC) to densify the loose in-situ soil.
- Localised insitu densification may be required should loose pockets be encountered in the excavation floor.
- Excavated material may be stockpiled based on material reuse requirements.
- The excavation side slopes should not be steeper than 1V:3H to prevent side wall collapse.
- Provision should be considered for a protective layer below the barrier system.
- Localised intermediate to hard rock excavations may be anticipated from a depth of 2.6m below surface in very dense silicified alluvium or pegmatite vein (as encountered in RWDTP5).

11. REFERENCES

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12. CERTIFICATION

This report was prepared and reviewed by the undersigned.

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Approval that this document adheres to Knight Piésold (Pty) Ltd Quality Systems: RF

Table 1: Summary of Previous Investigation Test Pits (TSF)

TEST PIT NO.	TOTAL DEPTH (m)	DEPTHS OF LAYERS (m) - (m)					
		Transported Soils	Pedogenic Soils			Residual Soils	Bedrock
		Aeolian	Nodular Calcrete	Honeycomb Calcrete	Hardpan Calcrete/ Ferricrete*	Residual/ Very Soft Rock Gneiss	Soft Rock Gneiss
P21	0.3	0 – 0.3	-	0 – 0.3*	0.3*+ R	-	-
P22	2.4	0 – 0.1	0.6 – 1.4	0.1 – 0.6	-	1.4 – 2.4	2.4+ R
P23	1.8	0 – 0.1	0.3 – 0.7	0.1 – 0.3	-	0.7 – 1.8	1.8+ R
P24	1.6	0 – 0.2	0.2 – 0.6	-	-	0.6 – 1.6	1.6+ R
P25	1.4	0 – 0.6	-	-	-	0.6 – 1.2	1.2 – 1.4+ R
P26	1.5	0 – 0.1	-	-	-	0.1 – 1.5	1.5+ R
P27	1.0	0 – 0.4	-	-	-	0.4 – 1.0	1.0+ R
P28	0.2	0 – 0.1	-	0.1 – 0.2*	0.2*+ R	-	-
P29	0.1	0 – 0.1	-	-	0.1*+ R	-	-
P30	0.1	0 – 0.1	-	-	0.1*+ R	-	-
P31	1.0	0 – 0.3	-	0.3 – 0.7	-	0.7 – 1.0	1.0 + R
P32	1.9	0 – 0.2	0.2 – 0.7	-	-	0.7 – 1.9	1.9+ R
P33	0.1	-	-	0 – 0.1	0.1*+ R	-	-

Table 2: Summary of Investigation Test Pits (TSF)

Test Pit No.	Total depth (m)	Thickness of Layers (m) – (m)											
		Transported Soil		Residual Soil			Rock						
		Fill/ Alluvium*	Colluvium (*calcified)	Nodular/ Honeycomb/ Hardpan Calcrete	Nodular Calcrete	Granite/ Gneiss (*Calcified)	Gneiss with pegmatite veins			Granite/ Pegmatite			Quartzite/ Pegmatite
							Soft rock	Medium hard rock	Hard rock (*very hard rock)	Soft rock	Medium hard rock	Hard rock	Medium hard rock
TP201	3.2	-	-	0 - 0.4	0.4 - 1.1	-	1.1 - 3.2	-	*3.2+R	-	-	-	-
TP202	2.7	-	-	0 - 0.4	0.4 - 0.9	-	-	0.9-2.7+R	-	-	-	-	-
TP203	1.5	0 - 0.4	-	-	-	-	-	0.4 - 1.5+R	-	-	-	-	-
TP204	2.6	0 - 0.5*	-	-	-	-	-	0.5 - 2.6+R	-	-	-	-	-
TP205	1.6	0 - 0.4	-	-	-	-	-	0.4 - 1.6+R	-	-	-	-	-
TP206	1.4	0 - 0.4	-	-	-	-	0.4 - 1.4	-	-	-	-	1.4+R	-
TP207	3.3	0 - 3.0	-	-	-	-	-	3.0 - 3.3+R	-	-	-	-	-
TP208	3.2	0 - 2.0	-	-	-	-	-	-	-	-	-	-	2.0 - 3.2+R
TP209	2.5	-	-	0 - 0.5	0.5 - 1.2	-	-	1.6 - 2.5+R	-	-	-	-	1.2 - 1.6
TP210	3.2	-	-	0 - 1.0	-	-	1.0 - 3.2	3.2+R	-	-	-	-	-
TP211	2.5	-	0 - 0.2	-	-	-	0.6 - 2.5	2.5+R	-	-	0.2 - 0.6	-	-
TP212	2.3	-	0 - 0.2	-	-	*0.2 - 0.7	-	2.0 - 2.3+R	-	0.7 - 2.0	-	-	-
TP213	1.2	-	0 - 0.1	0.1 - 0.4	-	*0.4 - 1.2	-	-	*1.2+R	-	-	-	-
TP214	2.1	-	*0 - 0.4	-	-	-	-	0.4 - 2.1+R	-	-	-	-	-
TP215	1.9	*0 - 0.7	-	-	-	0.7 - 1.1	-	1.1 - 1.9+R	-	-	-	-	-
TP216	1.1	*0 - 0.3	-	-	-	-	0.3 - 0.7	0.7 - 1.1	1.1+R	-	-	-	-

Table 2. Summary of Investigation Test Pits (TSF) (continued)

Test Pit No.	Total depth (m)	Thickness of Layers (m) – (m)											
		Transported Soil		Residual Soil			Rock						
		Fill/ Alluvium*	Colluvium (*calcified)	Nodular/ Honeycomb/ Hardpan Calcrete	Nodular Calcrete	Granite/ Gneiss (*Calcified)	Gneiss with pegmatite veins			Granite/ Pegmatite			Quartzite/ Pegmatite
TP217	3.9	-	0 - 0.1	0.1 - 0.7	-	0.7 - 1.9	1.9 - 3.9	3.9+R	-	-	-	-	-
TP218	0.1	*0 - 0.1	-	0.1+R	-	-	-	-	-	-	-	-	-
TP219	1.7	*0 - 0.2	-	-	-	-	0.2 - 1.7	1.7+R	-	-	-	-	-
TP220	0.8	*0 - 0.4	-	-	-	-	0.4 - 0.8	0.8+R	-	-	-	-	-
TP221	0.15	*0 - 0.1	-	-	-	-	-	0.1 - 0.15	0.15+R	-	-	-	-
TP222	0.8	*0 - 0.1	-	-	-	-	0.1 - 0.8	0.8+R	-	-	-	-	-
TP223	0.25	*0 - 0.2	-	-	-	-	-	0.2 - 0.25+R	-	-	-	-	-
TP224	0.8	*0 - 0.1	-	-	-	-	0.1 - 0.8	0.8+R	-	-	-	-	-
TP225	2.2	*0 - 0.4	-	-	-	-	0.4 - 2.2	2.2+R	-	-	-	-	-
TP226	0.1	*0 - 0.1	-	-	-	-	-	0.1+R	-	-	-	-	-
TP227	2.3	*0 - 0.7	-	-	-	-	0.7 - 2.3	2.3+R	-	-	-	-	-
TP228	0.35	*0 - 0.3	-	-	-	-	-	0.3 - 0.35+R	-	-	-	-	-
TP229	0.8	*0 - 0.4	-	-	-	-	-	0.4 - 0.8+R	-	-	-	-	-
TP230	0.8	*0 - 0.3	-	-	-	-	-	0.3 - 0.8+R	-	-	-	-	-
TP231	2.7	*0 - 0.5	-	-	-	-	-	1.1 - 2.7+R	-	-	-	-	0.5 - 1.1
TP232	0	-	-	-	-	-	-	0+R	-	-	-	-	-
TP233	1.9	*0 - 0.3	-	-	-	-	0.3 - 1.9	1.9+R	-	-	-	-	-

Note : R - Refusal

Table 3: Summary of Boreholes

BH No.	TOTAL DEPTH (m)	THICKNESS OF LAYERS (m) - (m)							
		TRANSPORTED SOILS				ROCK			
		FILL	Alluvium (*Calcified)	Silicified Alluvium	Calcrete Cobbles and Boulders	Gneiss			
						Very soft rock	Soft rock	Hard rock	Very hard rock
TSFBH1	11.5	-	0 - 1.30	-	-	1.3 - 6.14	6.14 - 11.5	-	-
TSFBH2	6.86	0 - 1.3	-	-	-	-	-	1.3 - 1.75	1.75 - 6.86
RWDBH3	14.13	-	0 - 0.3 *0.85 - 1.5	1.5 - 12.15	0.3 - 0.85	-	12.15 - 14.13	-	-

Table 4: Summary of Investigation Test Pits (RWD)

Test Pit No.	Total depth (m)	Thickness of Layers (m) – (m)			
		Transported Soil		Pedogenic Soil	
		Alluvium	Silicified Alluvium	Nodular/ Honeycomb/ Hardpan Calcrete	Nodular Calcrete
RWDTP1	3.4	0 - 0.1	1.0 - 3.4+R	0.45 - 1.0	0.1 - 0.45
RWDTP2	3.6	0 - 0.1	1.4 - 3.6+R	0.1 - 1.4	-
RWDTP3	3.0	0 - 0.2	3.0+R	0.2 - 3.0	-
RWDTP4	2.8	0 - 0.2	1.2 - 2.8+R	0.2 - 1.2	-
RWDTP5	2.6	0 - 0.1	1.3 - 2.6	0.1 - 0.5	0.5 - 1.3
RWDTP6	2.8	0 - 0.1	1.5 - 2.8+R	0.1 - 0.5	0.5 - 1.5
RWDTP7	3.3	0 - 0.1	1.6 - 3.2+R	0.1 - 0.6	0.6 - 1.6
RWDTP8	2.9	0 - 0.1	1.2 - 2.9+R	0.1 - 1.2	-

Note : R - Refusal

Table 5: Summary of Laboratory Test Results

Sample		Grading %				Atterberg Limits %			PI (Whole Sample)	GM	PE	AASHTO	USCS	Proctor Compaction		Peak Shear Box Strength Parameters		CBR (ASTM D1883-16)				COLTO	pH	Electrical conductivity (S/m)	Permeability (m/sec)	Material Description
No.	Depth (m-m)	Gravel	Sand	Silt	Clay	LL	PI	LS						MDD (kg/m^3)	OMC (%)	Friction Angle (°)	Cohesion kPa	% Swell	90%	93%	95%					
Return Water Dam																										
RWDTP1/1	0.1 - 0.45	59	32	6	3	33	10	5.5	3	2.24	Low	A-2-4	GP-GC	-	-	-	-	-	-	-	-	-	-	-	-	Nodular Calcrete
RWDTP1/2	1.0 - 2.3	43	49	6	2	40	13	6.0	4	1.99	Low	A-2-6	SP-SC	-	-	-	-	-	-	-	-	-	-	-	-	Silicified Alluvium
RWDTP3/1	0.0 - 0.2	21	71	6	2	-	NP	0.0	-	1.66	Low	A-1-b	SW-SM	-	-	-	-	-	-	-	-	-	-	-	-	Alluvium
RWDTP3/2	0.2 - 1.2	35	43	12	10	46	18	9.0	8	1.68	Low	A-2-7	SC	-	-	-	-	-	-	-	-	-	-	-	-	Nodular Calcrete with calcrete cobbles and boulders
RWDTP3/3	1.8 - 3.0	30	57	11	2	37	13	6.5	5	1.74	Low	A-2-6	SC	1848	14.6	38	0	0.9	8	13	18	G8	-	-	-	Calcified Alluvium
RWDTP7/1	0.1 - 0.6	65	29	4	2	29	8	4.5	2	2.35	Low	A-2-4	GP-GC	-	-	-	-	-	-	-	-	-	-	-	-	Nodular and Honeycomb Calcrete
RWDTP7/2	0.6 - 1.6	47	41	10	2	42	15	7.5	5	2	Low	A-2-7	SC	1803	15.0	38	0	0.2	15	23	30	G7	8	0.191	-	Nodular Calcrete
RWDTP7/3	1.6 - 1.9	37	53	8	2	41	15	7.0	6	1.86	Low	A-2-7	SP-SC	1832	13.6	36	0	0.4	12	19	26	G7	8.1	0.323	5.79×10^{-7}	Silicified Alluvium
Tailing Storage Facility																										
TP203/1	0.0 - 0.4	49	44	5	2	-	SP	0.5	-	2.14	Low	A-1-b	SP-SM	-	-	-	-	-	-	-	-	-	7.7	0.14	-	Fill
TP203/2	0.4 - 0.9	42	53	3	2	-	SP	0.5	-	2.11	Low	A-1-b	SP-SM	-	-	-	-	-	-	-	-	-	-	-	-	Soft rock Gneiss
TP205/1	0.0 - 0.4	54	33	8	5	33	11	6.5	3	2.1	Low	A-2-6	SC	1910	12.4	38	0	0.2	12	18	23	G7	7.9	0.038	1.38×10^{-8}	Calcified Alluvium
TP205/2	0.4 - 1.2	60	37	2	1	-	NP	0.0	-	2.39	Low	A-1-a	SW	1942	11.0	41	0	0	18	28	38	G6	8.3	0.021	1.26×10^{-8}	Soft rock Gneiss
TP215/1	0.0 - 0.7	52	43	4	1	-	SP	0.5	-	2.25	Low	A-1-a	SP-SM	1903	11.7	36	13	0	10	16	23	G7	-	-	-	Ferruginised coarse Alluvium
TP220/1	0.0 - 0.4	26	63	9	2	-	NP	0.0	-	1.65	Low	A-1-b	SM	-	-	-	-	-	-	-	-	-	-	-	-	Coarse Alluvium

Notes:

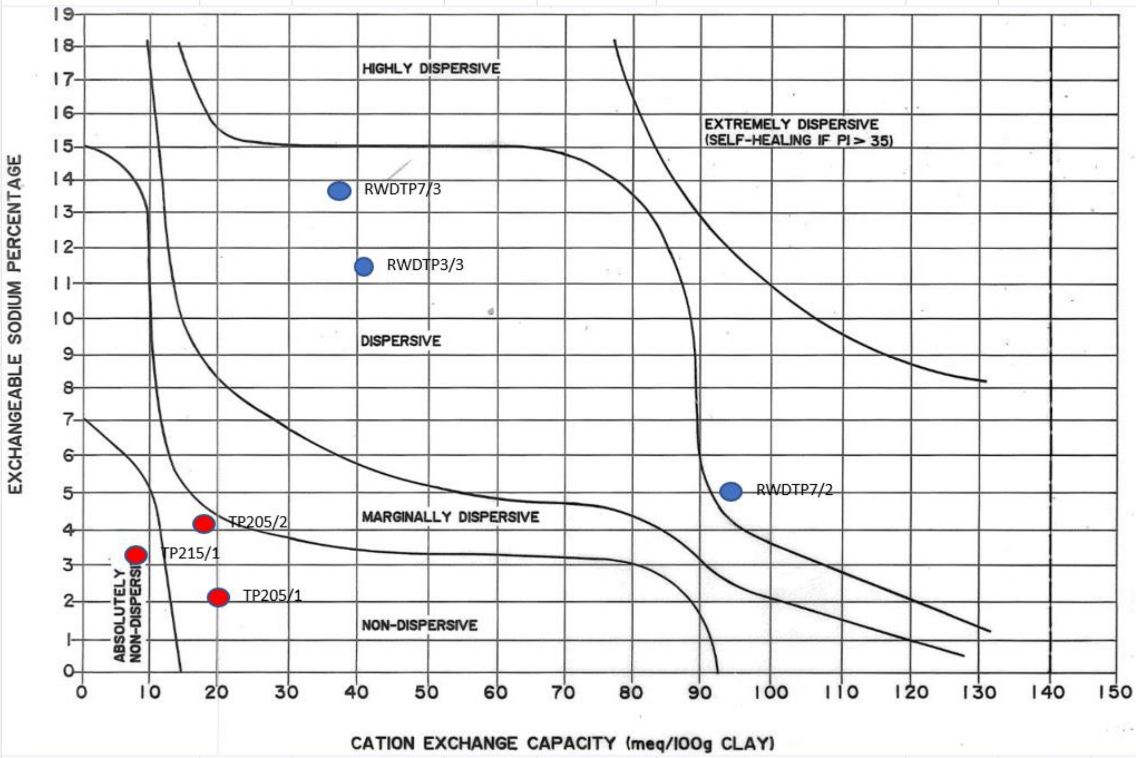
LL : Liquid Limit
PI : Plasticity Index
LS : Linear Shrinkage
GM : Grading Modulus
PE : Potential Expansiveness

USC : Unified Soil Classification
CBR : California Bearing Ratio
MDD : Maximum Dry Density
OMC : Optimum Moisture Content

GP : Poorly graded gravel
GC : Clayey gravel
SP : Poorly graded sand

SC : Clayey sand
SW : Well graded sand
SM : Silty sand

Table 6: Summary of Soil Dispersivity Results



CHEMICAL DISPERSION			
Sample	**ESP**	**CEC**	**Described as (Gerber and Harmse (1987))**
	%	**cmol(+)/kg**	
RWDTP3 /3	11.5	41.66	Dispersive
RWDTP7 /2	5.01	80.32	Dispersive
RWDTP7 /3	13.75	33.62	Dispersive
TP205 /1	2.05	17.11	Non-dispersive
TP205 /2	4.12	15.49	Non-dispersive
TP215 /1	3.21	8.67	Absolutely non-dispersive

Note: mEq/100g is numerically equal to cmol/kg

DOUBLE HYDROMETER		
SAMPLE	**Dispersion ratio**	**Described as (Bell and Walker (2000))**
	%	
RWDTP3 /3	12	Non-dispersive
RWDTP7 /2	27	Slightly dispersive
RWDTP7 /3	36	Moderately dispersive
TP205 /1	1	Non-dispersive
TP205 /2	6	Non-dispersive
TP215 /1	0	Non-dispersive

APPENDIX A

Geophysical Report

APPENDIX B

Test Pit Profiles

APPENDIX C

Rotary Core Borehole logs and Photographs

APPENDIX D

Laboratory Test Results