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The design of a geocomposite drainage layer to collect effluent from the coal production process

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Abstract

A Mine in Mpumalanga required a drainage layer to collect effluent from the coal mining process as part of the layer works beneath the stockpile pads and discard dumps at the mine. The drainage layer was designed for a 20-year design life considering various factors affecting drainage and a required flow rate of 0.1m3/h/m. The allowable long-term flow rate through the drain was calculated using Maccaferri Macro software and the most suitable drainage product was selected. The factors of safety for the drainage options were between 1.01 and 4.6 for the layer works. The composite drainage consisted of 400m long and 2.15m wide strip. The use of the geocomposite drainage layer was determined to be the most suited solution for the layer works of both the stockpile pads and the discard dumps based on the long-term drainage and safety factors of the 20-year design life.

Keywords: *Geosynthetics, Drainage, Geotechniques, Mining, Geocomposite*

1 Introduction

Maccaferri SA (Pty) Ltd was approached by the client on the 27th of July 2017 to submit a proposal for the drainage of the effluent discharge for the stockpile pad and discard dump at a mine in the Bronkhorstspruit region, South Africa.

The drainage design was based on the drainage length, drainage slope, discharge, loadings, design life and drainage rate provided by the client for a design life of 20 years.

The following is recommended:
<u>Stockpile Pad</u>

MacDrain ® W1061, W1071, W1081, W1091 or W1101 in accordance with the attached **Technical Data Sheets.**

Table 1: Factors of safety Summary - Stockpile Pad

Solution	Factor of Safety
W 1061	2.304
W 1071	2.116
W 1081	2.909
W 1091	4.431
W 1101	4.574

Discard Dumps
MacDrain ® W1091 or W1101 in accordance with the attached **Technical Data Sheets.**

Table 2: Factors of Safety Summary - Discard Dumps

Solution	Factor of Safety
W 1091	1.073
W 1101	1.510

Barrier Replacement
MacDrain ® acts as a drainage layer and it might work as a barrier system if one side of the MacDrain ® is use with a geomembrane (type 1XXM), however this membrane does not comply with Department of Water and Sanitation barrier system, therefore it will not be recommended.

The proposed solution is 1.5m wide strips of MacDrain ® placed at 10m intervals for the stockpile pads and at 20m intervals for the discard dumps.

2 Problem Statement

The proposed stockpile pads and discard dumps required a drainage layer to collect effluent from coal before loading on top of two 150mm sodium bentonite modified clay layers compacted to 95% MOD AASHTO at OMC as well as a bitumen tack coat of 1.5mm thick acting as a barrier system. These layers are placed on top of 110mm drainage pipe with the pipes acting as a final leakage detection. The MacDrain's purpose is to act as the primary surface drainage for the layer works. The pipes are placed at 80m intervals.

For the stockpile, a 300mm coarse discard protection layer will be placed on top of the MacDrain ® with an additional 300mm sacrificial layer of selected coal product placed on top of the coarse discard layer.

For the discard dump, the MacDrain ® is placed under 600mm coarse discard protection layer provision made for 40m of compacted material over the design life of the dump.

2.1 Design Requirements

2.1.1 Stockpile Pads

400 m long strips of MacDrain ® are to be placed at a 2-3% slope, covered by 600mm coal discard with 80-ton bell trucks maneuvering on the stockpile pad. Long Term (10-20 years) drainage rate required at the lower end is 1m3/h for 10m spacing of drains ie. 0.1m3/h/m width.

2.1.2 Discard Dumps

400 m long strips of MacDrain ® are to be placed at a 2-3% slope, covered by 40m coal discard at 1600kg/m3 (wet). Long Term (10-20 years) drainage rate required at the lower end is 2m3/h for 20m spacing of drains ie. 0.1m3/h/m width.

Design Life: 20 years.

For economic reasons the client requested strips at 10 to 20m apart, unless the drain can be regarded as a barrier, whereby it can replace one of the two barriers required if economically feasible.

3 Design Procedure

3.1 Selection of contact surface

Before the design procedure is performed, the type of contact of the materials with the faces of the geocomposite must be considered. The contact surface is important as it describes the level of intrusion of materials into the drainage core with soft materials describing a more pronounced intrusion and hard materials virtually no intrusion.

The definitions of each type of contact are found in Table 3 below:

Table 3: Selection of contact surfaces

Rigid–Rigid contacts	Rigid–Soft contacts	Soft–Soft contacts
- GCD for leakage detection in landfills, between two geomembranes - GCD between shotcrete and structural arch in tunnels	- GCD behind retaining walls - GCD in a capping package or for leachate collection in landfills, in contact with geomembrane at the bottom and soil/gravel on top - GCD for roof gardens or vegetated terraces	- GCD inside a draining trench - GCD under a road or railway embankment - GCD in parking areas - GCD behind a reinforced slope

From the table, this design was performed for a rigid-soft contact.

3.2 Dynamic Viscosity

The dynamic viscosity (ή) is selected from Table 4 below:

Table 4: Selection of dynamic viscosity

T (°C)	η (cP = 10^{-3} Pa·s)
0	1.787
5	1.519
10	1.307
15	1.139
20	1.005
25	0.8904
30	0.7975
35	0.7194
40	0.6529
45	0.596
50	0.5468
60	0.4665
70	0.4042
80	0.3547
90	0.3147
100	0.2818

From the table, for 20◦C effluent, the dynamic viscosity is 1.005.

3.3 Height of rainfall

The height of rainfall describes the expected rainfall in mm for the area in which the MacDrain will be placed. The rainfall will have an associated flow rate which is considered in the final long-term flow rate design of the drain.

The height of rainfall is determined using:

$$h_r = at^n$$

Where:
-n = Exponent of the pluviometric curve
-a = Parameter of pluviometric curve (mm/h-n)
-t = Duration of rainfall (h)

For this design, there was no additional rainfall data received thus the height is assumed negligible.

The rainfall generated flow is thus also assumed negligible.

3.4 Surficial input flow of MacDrain

The surficial flow is determined using:

$$Q_S = \frac{D}{3600} \quad \text{[l/s/m]}$$

Where:
-D = Discharge

Thus, QS = 100/3600 = 0.0278 l/s/m

It is considered that Qs will be the drainage requirement of the geocomposite drain, further referred to as QG.

3.5 Factors of Safety

The guideline factors of safety are listed in the table below:

Table 5: Guideline factors of safety

Term	Description	Suggested range for MacDrain® geocomposites
RF_{in}	Reduction Factor for intrusion of the filter geotextiles into the draining core	1.0 – 1.5
RF_{cr}	Reduction Factor for thickness change due to compressive creep of the core	1.2 – 1.5
RF_{cc}	Reduction Factor for pore/volume reduction due to chemical clogging **	1.0 – 1.3
RF_{bc}	Reduction Factor for pore/volume reduction due to biological clogging**	1.0 – 1.3
Π RF	**Product of all Reduction Factors for the site-specific conditions**	**1.20 – 4.0**
* values can change according to the type of the core and also according to the type of filtering geotextile used ** values are related to the type of liquid / fluid to be drained and to its nature (clean water, polluted water, leachate, etc)		

From the Table, the various factors of safety can be determined with leachate design taking the highest value from the table except for biological clogging for which this design will have none.

The factors of safety are as follows:
- Intrusion = 1.5
- Chemical Clogging = 1.3
- Biological Clogging = 1

3.5.1 Compressive Creep

The factor of Safety for compressive creep is found in Table 6 below:

Table 6: Factors of safety for creep

RF_{cr-Q}	50 kPa	100 kPa	200 kPa	500 kPa
1 year	1,011	1,061	1,118	1,771
5 years	1,016	1,071	1,136	1,894
10 years	1,021	1,080	1,153	1,956
20 years	1,026	1,085	1,161	2,026
50 years	1,031	1,090	1,170	2,148
≥ 100 years	1,036	1,099	1,185	2,242

These values are based on tests run under normal compressive loads using both the Stepped Isothermal Method (SIM) of time-temperature superposition (TTS) compressive creep tests and conventional isothermal compressive creep tests performed at room temperature. The testing method used were the ASTM D7361-07 (2012), Accelerated Compressive Creep of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method and the ISO 25619-1:2008, Geosynthetics - Determination of Compressive behavior - Part 1: Compressive Creep Properties.

The design compressive creep factor used was the maximum value for a 20-year design life of 2.026.

3.6 Long Term Flow Rate

The Long Term flow rate of the geocomposite drain is determined as follows:

$$Q_L = \frac{F_{lr} * Q_S}{RFin * RFcr * RFcc * RFbc} \text{ [l/s/m]}$$

Where:
-QL = available long term flow rate for the geocomposite;
-QGCD = short term flow rate obtained from laboratory tests of geocomposite drain;
-RFin = Reduction Factor for the intrusion of filter geotextiles into the draining core;
-RFcr-Q = Reduction Factor for the compressive creep of the geocomposite;
-RFcc = Reduction Factor for chemical clogging of the draining core
-RFbc = Reduction Factor for biological clogging of the draining core
-Flr = empirical factor to be applied when the test results for QL are available for contact conditions different from the project conditions

The final factor of safety is calculated by using:

$$FS_G = \frac{Q_L}{Q_G} \geq 1$$

4 Results

Considering the input parameters provided by the client, the following results were determined following a design using MacFlow ®. The full design reports can be found in Appendices A and B.

4.1 Stockpile Pad Lining

Table 7: Design Results for the Stockpile Pads

MACDRAIN W EVALUATION - CONTACT RIGID / SOFT					
MACDRAIN	CONTACT	HYDRAULIC GRADIENT i	**Q_L (l/s/m)**	FS_u = Q_L / Q_G	**OK/NO**
W 1041	R / S	0.030	**0.087**	0.789	**NOT SUITABLE**
W 1051	R / S	0.030	**0.092**	0.834	**NOT SUITABLE**
W 1061	R / S	0.030	**0.253**	2.304	**OK**
W 1071	R / S	0.030	**0.238**	2.166	**OK**
W 1081	R / S	0.030	**0.319**	2.909	**OK**
W 1091	R / S	0.030	**0.486**	4.431	**OK**
W 1101	R / S	0.030	**0.502**	4.574	**OK**

From Table 7 it is evident that MacDrain ® W1061, W1071, W1081, W1091 and W1101 are suitable for the stockpile pads.

4.2 Discard Dump Lining

Table 8: Design Results for the Discard Dumps

MACDRAIN W EVALUATION - CONTACT RIGID / SOFT					
MACDRAIN	CONTACT	HYDRAULIC GRADIENT i	**Q_L (l/s/m)**	FS_u = Q_L / Q_G	**OK/NO**
W 1041	R / S	0.030	**0.019**	0.175	**NOT SUITABLE**
W 1051	R / S	0.030	**0.015**	0.139	**NOT SUITABLE**
W 1061	R / S	0.030	**0.014**	0.124	**NOT SUITABLE**
W 1071	R / S	0.030	**0.019**	0.170	**NOT SUITABLE**
W 1081	R / S	0.030	**0.040**	0.361	**NOT SUITABLE**
W 1091	R / S	0.030	**0.118**	1.073	**OK**
W 1101	R / S	0.030	**0.166**	1.510	**OK**

From Table 8 it is evident, that for the spacing requested at the discard dumps, the MacDrain ® W1091 and W1101 are suitable discard dumps.

6 Conclusion

The use of MacDrain ® in the application of drainage for stockpile pads and discard dumps for the mine was considered is recommended, supported by factors of safety between 2.304 and 4.574 for the stockpile and 1.073 and 1.510 for the discard dump depending on the type of MacDrain ® considered.

Detailed designs were performed using Maccaferri's MacFlow ® design software and taking into account the design parameters provided by the client. From these designs, recommendations were made by Maccaferri on which type of MacDrain ® was applicable for each application.

References

ASTM D7361-07(2012), Standard Test Method for Accelerated Compressive Creep of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method, ASTM International, West Conshohocken, PA, 2012, www.astm.org

ISO 25619-1:2008, Geosynthetics -- Determination of compression behaviour -- Part 1: Compressive creep properties, International Organization for Standardization, Vernier, Geneva, 2008, www.iso.org

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Appendix A – Design Table for Stockpile Pad

MACCAFERRI MACFLOW

DESIGN OF MACDRAIN GEOCOMPOSITES FOR DRAINAGE IN SUB-HORIZONTAL FLOW APPLICATIONS

GEOMETRY	SYMBOL	VALUE	UNIT
MacDrain length along slope	L	400.00	m
Slope of MacDrain (V / H ≤ 10 %)	V / H	3.00	%
Coefficient of infiltration	f	1.00	-

SOIL / MATERIAL ON MACDRAIN	SYMBOL	VALUE	UNIT
Saturated unit weight	γ	16.00	kN/m^3
Thickness	H	0.60	m
Distributed surcharge	q	15.00	kN/m^2

WATER OR LIQUID TO BE DRAINED	SYMBOL	VALUE	UNIT
Water temperature	T	20.0	°C
Given dynamic viscosity of liquid at the design temperature (set = 0 if water has to be used)	η	1.01	cP = 10^{-3} Pa·s

RAIN	SYMBOL	VALUE	UNIT
Pluviometric curve h = a t^n			
Parameter a	a	1.00	$mm/hour^{-n}$
Exponent	n	0.00	-
Duration of critical rain	t	1.00	hours
Given rain height in 1 hour (set = 0 if pluviometric curve has to be used)	h_r	0.00	mm

ADDITIONAL SURFICIAL FLOW RATE	SYMBOL	VALUE	UNIT
Surficial input flow in MacDrain	Qs	0.0278	l/s/m

FACTORS OF SAFETY	SYMBOL	VALUE	UNIT
FoS for input flow	FSq	1.00	-
RF for gtx intrusion	RFin	1.50	-
RF for compressive creep	RFcr	2.03	-
RF for chemical clogging	RFcc	1.30	-
RF for biological clogging	RFbc	1.00	-

CALCULATIONS	SYMBOL	VALUE	UNIT
Maximum pressure on MacDrain	**p**	**24.60**	**kPa**
Hydraulic gradient	**i**	**0.030**	**-**
Rain height for design duration	h_r	1.00	mm
Rain intensity for design duration	j_r	1.00	mm/h
Input flow in MacDrain	Qin	0.028	l/s/m
Design long term input flow for MacDrain	**Qd**	**0.110**	**l/s/m**
Reference water temperature	T_1	20.0	°C
Reference dynamic viscosity	η (T_1)	1.005	cP = 10^{-3} Pa·s
Design dynamic viscosity	η (T_2)	1.005	cP = 10^{-3} Pa·s
Correction for liquid temperature and viscosity	**CT**	**1.000**	**-**

MACDRAIN W EVALUATION - CONTACT RIGID / SOFT					
MACDRAIN	CONTACT	HYDRAULIC GRADIENT i	**Q_L (l/s/m)**	FS_u = Q_L / Q_G	**OK/NO**
W 1041	R / S	0.030	**0.087**	0.789	**NOT SUITABLE**
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W 1071	R / S	0.030	**0.238**	2.166	**OK**
W 1081	R / S	0.030	**0.319**	2.909	**OK**
W 1091	R / S	0.030	**0.486**	4.431	**OK**
W 1101	R / S	0.030	**0.502**	4.574	**OK**

Appendix B – Design Table for Discard Dumps

MACCAFERRI GEOSYNTHETICS

MACCAFERRI MACFLOW

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GEOMETRY	SYMBOL	VALUE	UNIT
MacDrain length along slope	L	400.00	m
Slope of MacDrain (V / H ≤ 10 %)	V / H	3.00	%
Coefficient of infiltration	f	1.00	-

SOIL / MATERIAL ON MACDRAIN	SYMBOL	VALUE	UNIT
Saturated unit weight	γ	16.00	kN/m^3
Thickness	H	37.50	m
Distributed surcharge	q	0.00	kN/m^2

WATER OR LIQUID TO BE DRAINED	SYMBOL	VALUE	UNIT
Water temperature	T	20.0	°C
Given dynamic viscosity of liquid at the design temperature (set = 0 if water has to be used)	η	1.01	cP = 10^{-3} Pa·s

RAIN	SYMBOL	VALUE	UNIT
Pluviometric curve h = a t^n			
Parameter a	a	1.00	$mm/hour^{-n}$
Exponent	n	0.00	-
Duration of critical rain	t	1.00	hours
Given rain height in 1 hour (set = 0 if pluviometric curve has to be used)	h_r	0.00	mm

ADDITIONAL SURFICIAL FLOW RATE	SYMBOL	VALUE	UNIT
Surficial input flow in MacDrain	Qs	0.0278	l/s/m

FACTORS OF SAFETY	SYMBOL	VALUE	UNIT
FoS for input flow	FSq	1.00	-
RF for gtx intrusion	RFin	1.50	-
RF for compressive creep	RFcr	2.03	-
RF for chemical clogging	RFcc	1.30	-
RF for biological clogging	RFbc	1.00	-

CALCULATIONS	SYMBOL	VALUE	UNIT
Maximum pressure on MacDrain	**p**	**600.00**	**kPa**
Hydraulic gradient	**i**	**0.030**	**-**
Rain height for design duration	h_r	1.00	mm

Rain intensity for design duration	j_r	1.00	mm/h
Input flow in MacDrain	Qin	0.028	l/s/m
Design long term input flow for MacDrain	**Qd**	**0.110**	**l/s/m**
Reference water temperature	T_1	20.0	°C
Reference dynamic viscosity	η (T_1)	1.005	cP = 10^{-3} Pa·s
Design dynamic viscosity	η (T_2)	1.005	cP = 10^{-3} Pa·s
Correction for liquid temperature and viscosity	**CT**	**1.000**	**-**

MACDRAIN W EVALUATION - CONTACT RIGID / SOFT					
MACDRAIN	CONTACT	HYDRAULIC GRADIENT i	**Q_L (l/s/m)**	FS_u = Q_L / Q_G	**OK/NO**
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W 1051	R / S	0.030	**0.015**	0.139	**NOT SUITAB**
W 1061	R / S	0.030	**0.014**	0.124	**NOT SUITAB**
W 1071	R / S	0.030	**0.019**	0.170	**NOT SUITAB**
W 1081	R / S	0.030	**0.040**	0.361	**NOT SUITAB**
W 1091	R / S	0.030	**0.118**	1.073	**OK**
W 1101	R / S	0.030	**0.166**	1.510	**OK**