Soil Analysis Services

WORLD CLASS GEOTECHNICAL TESTING

Volatile Corrosion Inhibitor Dispensing System Troubleshooting and Filtration Design

Report No. GTC/NDT/20-010/R001
Client CORTEC Middle East
Project CORTEC In-house R&D

REVISION	DATE	PREPARED BY	APPROVED BY
0	26 January 2021	Majed Karam	Majed Karam

GTC/NDT/20-010/R001/Rev 00
January 26, 2021

M/s CORTEC Middle East
Attention: Mr. Khalil Abed
Subject: VCI Dispensing System Troubleshooting and Filtration Design
Project: CORTEC In-house R&D

Dear Mr. Abed,

GTC is pleased to submit this report for the VCI Dispensing System Troubleshooting and Filtration Design experimental work conducted.

This report presents the scope of investigation and methods of in-situ tests, findings, conclusions and recommendations.
Should you require any further information, please do not hesitate to contact us at your convenience.

Yours Faithfully,

Eng Emad Sharif
Director

Email: emad.sharif@GTC-lab.com
Mobile: 050 456 6264

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1 INTRODUCTION

The irrigation system adopted by CORTEC for dispersing their VCI liquid suspension is not performing as intended on a specific site. The irrigation system consists of Eurodrip 16 mm PC^2 PVC pipes sandwiched between 2 layers of compacted sand. The nominal degree of compaction of the sand is 95 %. The client has reported considerable reduction in the flow rate on site, particularly at the center of the distribution ring. It is suspected that the compaction activities, which effect is probably more pronounced at the center of the distribution ring, are affecting the flow of the liquid suspension through the pipes by blocking the openings in the pipes and by reducing the sand permeability beyond desirable levels. An experimental program was designed and executed in order to troubleshoot the system, as well as devise a solution for dispensing the VCI effectively. The welding-induced heat was also investigated by coupling experimental and numerical modeling techniques.

2 APPROACH & METHODOLOGY

2.1 STEADY-FLOW-RATE EXPERIMENTS

The test bed shown in Figure 1 was built. It consists of a 1 m x 1 m x 0.35 m wooden box with aluminum braces for support. One face has 4 hole openings that allow fitting the pipes to the pump. The hole openings are centered at the mid-height of the 0.35 m high panel. Thus, the test bed had 2 main sand layers: the bottom sand layer of dimension 1 m x 1 m x 0.17 m, and the top sand layer of dimension 1 m x 1 m x 0.15 m. Each layer was formed in 5 to 7 cm thickness increments. The sand used in the experiment is of similar type to that used on site. A modified proctor test, in accordance with standard specifications, was performed in order to determine the maximum dry density and corresponding optimum moisture content. Based on that information, and the moisture content of the sand, mixing of sand and additional required water was performed, followed by compaction using a steel compaction plate. The quality of compaction was controlled by monitoring the height of the resultant compacted layer, based on known desired density to achieve the target 95 % compaction. In order to have the closest fidelity to site conditions, CorroLogic® slurry was used in the experiments. Table 1 summarizes the characteristics of the sand used in the experiment. The corresponding soil report can be found in appendix.

TABLE 1 PHYSICAL CHARACTERISTICS OF SAND USED IN EXPERIMENT

Specification	Value	Standard
Maximum dry density	1.70 kg/m^3	BS 1377 Part 4
Optimum moisture content	16 %	BS 1377 Part 4
Moisture content	0.6 %	BS 1377 Part 2

A total of 4 modification states were evaluated. More modification states could be evaluated using the same experimental setup and instrumentation. The states are as follows:

1. no_modification: the Eurodrip® PC^2 PVC pipe was used with no modification whatsoever
2. gravel_thin_geotextile: a gravel filter (5-10 mm thick) was constructed around each opening in the PVC pipe with a 1-mm thick non-woven polypropylene geofabric
3. gravel_thick_geotextile: similar to the gravel_thin_geotextile, however a thick geofabric supplied by CORTEC was used

4. gravel_HDPE_thin_geotextile: the PVC pipe was slid in the center of a 50-mm diameter perforated HDPE tube. The tube was filled with gravel. A single layer of the 1-mm thick non-woven polypropylene geofabric was used to cover the HDPE tube

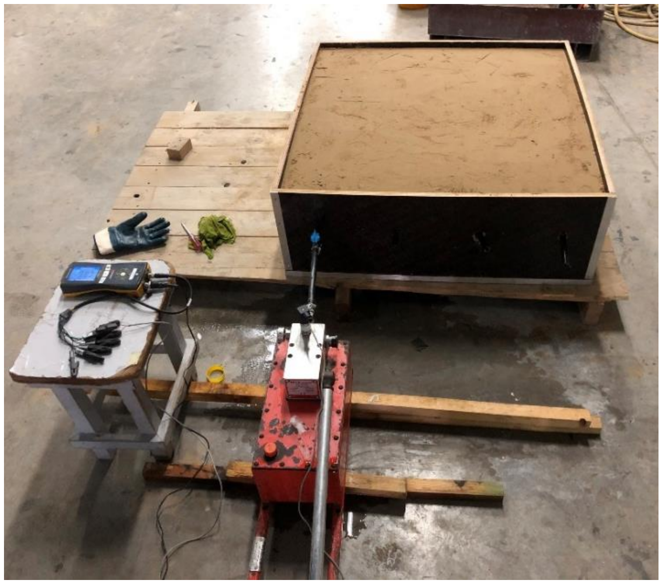


FIGURE 1 GENERAL VIEW OF TEST SETUP SHOWING TEST BED FILLED WITH COMPACTED SAND AND EMBEDDED PIPELINES, HYDRAULIC PUMP, PRESSURE TRANSDUCER, AND DATA LOGGER

FIGURE 2 PIPELINES WITH THE VARIOUS MODIFICATION STATES LAYING ON LAYER OF COMPACTED SAND. IMAGE TAKEN BEFORE FILLING AND COMPACTING THE TOP SAND LAYER

Figure 2 shows 4 pipelines, each fitted with one of the modification states, laying on a layer of compacted sand. Each pipeline and corresponding fittings were tested for leakage prior to testing. All pipelines and fittings used in the experiment passed the leakage test. The geotextiles used serve to confine the gravel used in the filter. The gravel used is shown in Figure 3, where it is laid on the thin geofabric as a single layer.

FIGURE 3 GRAVEL USED FOR FILTER FABRICATION LAID AS A SINGLE LAYER ON GEOFABRIC

Four pipes were installed in the test bed. All pipes prior to modification were identical and consist of 3 openings. In order to minimize boundary effects that might affect the flow of pumped liquid, all pipe openings were at least 10 cm away from any object or boundary. Once the top sand layer was placed and compacted up to the desired degree of compaction (95 %), the experimental trials began as follows:

1. Each pipeline was tested individually
2. Before each experimental trial, the pump reservoir was filled at capacity with the CorroLogic® slurry
3. The flow rate was controlled in a way to achieve the operational flow rate of the pipe
4. The pressure gauge was recorded at 30 seconds intervals for a period of 60 minutes
5. Once the 60 minutes elapsed, the pump was refilled with the CorroLogic® slurry using a graduated cylinder, allowing for the determination of the volume consumed over the 60-minute period

The parameter of interest in this experiment is the pressure build-up, and the ability of the pipeline modification to relieve the pressure. Pressure relieve relies on the increased permeability of the medium surrounding the pipe opening by having gravel, as well as increasing the effective contact surface area between the opening and the compacted sand. The experiment was later repeated for the no_modification and gravel_thin_geotextile modification states with sand compacted at 98 % compaction and post-optimum moisture state.

2.2 Assessment of Heat Dissipation

On-site steel plate welding activities raised concern on their potential effects on the integrity of the PVC pipes. In order to do so, the dissipation of welding-induced heat was studied experimentally. Unidirectional heat flow can be formulated as shown in Equation 1 below, where T is the temperature, D the heat diffusion coefficient (diffusivity), and z the direction of heat flow. Note that the diffusion coefficient as formulated accounts for conduction, convection, and radiation.

$$\frac{\partial T}{\partial t} = -D\frac{\partial^2 T}{\partial z^2} \qquad 1$$

The objective here is to safely simulate the site conditions during welding. An experimental approach was adopted to assess the heat dissipation, as follow:

1. A 1,500 W resistance heater was place in a rectangular steel container filled with 10 L of water. The base of the steel container measures 20 cm x 20 cm. The heater was turned on to heat up the water. The maximum temperature of the steel plate was 95 °C, kept constant for most of the experiment.
2. Thermocouples were placed in the sand at 5 cm and 10 cm from the bottom of the steel container along the centreline of the plate.
3. The resistor was kept on during a period of 4 hours, during which a DAQ system was recording the thermocouple readings at 1-min intervals.

The results of this experiment should be interpreted keeping the following in mind. First, is the value of maximum temperature reached at the source, as well as temperature history. The welding temperatures can be variable and depend on the welding practice adopted on site, as well as the conductivity and thermal mass of the welded steel plates. Second, the thickness of sand layer separating the heat source from the PVC pipe is different on site.

3 EXPERIMENTAL RESULTS

3.1 Steady-Flow-Rate Experiments

The following shows the pressure history during the one-hour steady-flow-rate experiment.

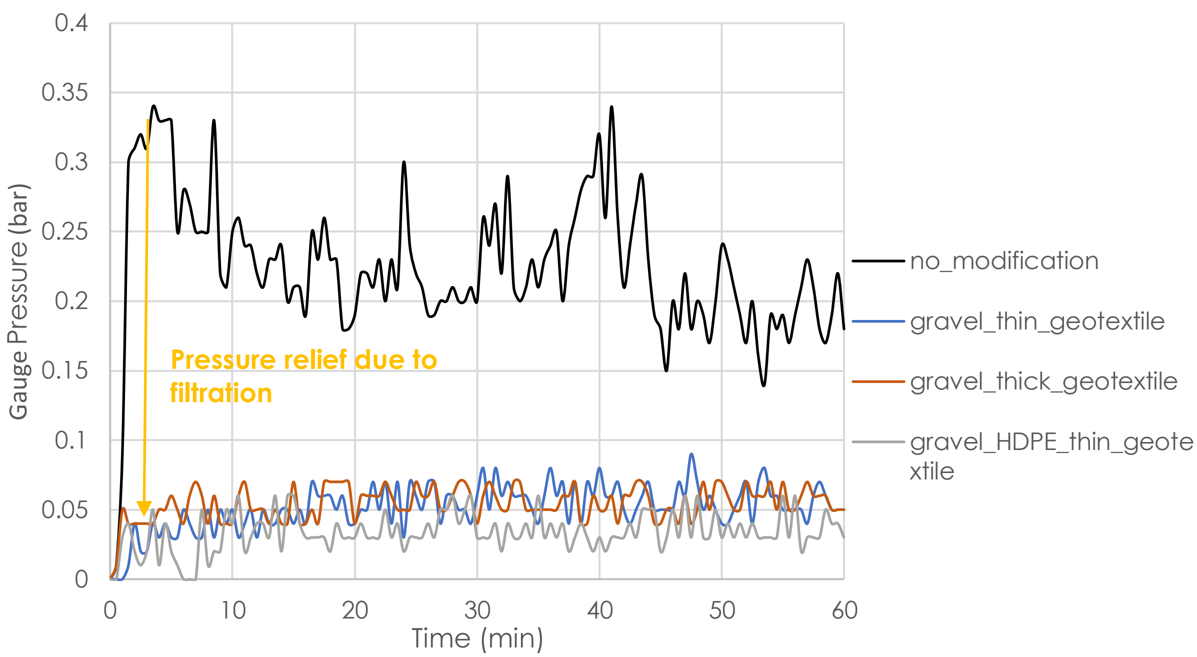


FIGURE 4 PRESSURE HISTORY IN STEADY-FLOW-RATE EXPERIMENTS

Table 2 summarizes the volume of CorroLogic® slurry consumed over the 60-min experiment. This is used for quality assurance purposes, as it is desired that all flow rates be similar in order to compare the pressure histories. The tabulated values are close to each other, thus a comparison based on pressure histories can be used for evaluating the filters.

TABLE 2 VOLUME OF CORROLOGIC® SLURRY CONSUMED OVER THE 60-MIN EXPERIMENT

Modification state	Volume flow (L)	Average flow rate per ring (L/h)
no_modification	8.70	2.9
gravel_thin_geotextile	8.65	2.88
gravel_thick_geotextile	8.85	2.95
gravel_HDPE_thin_geotextile	8.60	2.87

Figure 5 shows the results of the experiment when sand is compacted at 98 % with a moisture content post-optimum.

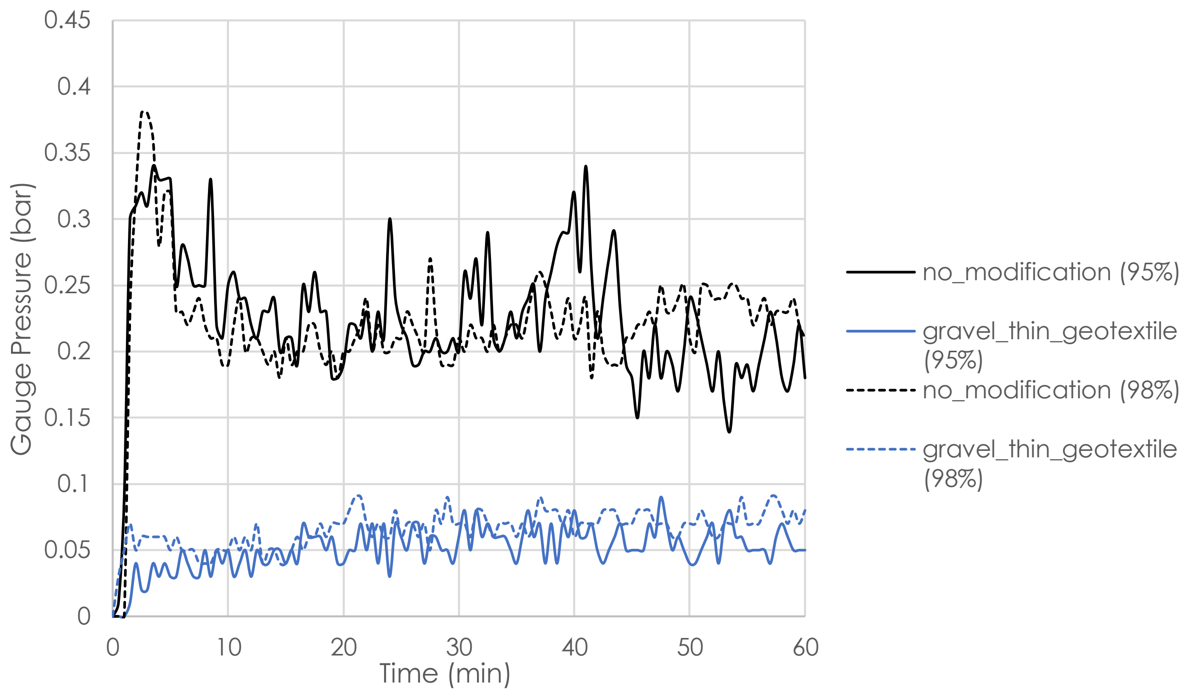


FIGURE 5 COMPARISON OF PRESSURE HISTORY FOR TWO SAND COMPACTION STATES TESTED

Once the experiments were completed, the top sand layer was carefully removed, and each pipe and its surroundings were visually inspected, looking for cavitation or sand washout. No evidence of disturbance to the sand was observed.

The effect of soil overburden was investigated by increasing the overburden height to 46 cm. The target of 50 cm could not be reached due the geometrical limitations of the test setup and shear stresses on the soil. The test setup is shown in Figure 6 below. The test lines of interest were no_modification and gravel_thin_geotextile, and were placed in the center, having identical boundary conditions during testing.

FIGURE 6 TEST SETUP FOR 46 CM OVERBURDEN HEIGHT

Figure 7 shows the pressure history during testing. The following is observed:

- The pressure buildup was higher than that of the previous rounds, also explaining the higher noise level;
- The filter was effective at dissipating the fluid and reducing the pressure to reach the target flow rate; and
- Flow rate values were the same as that of the other rounds of experiments.

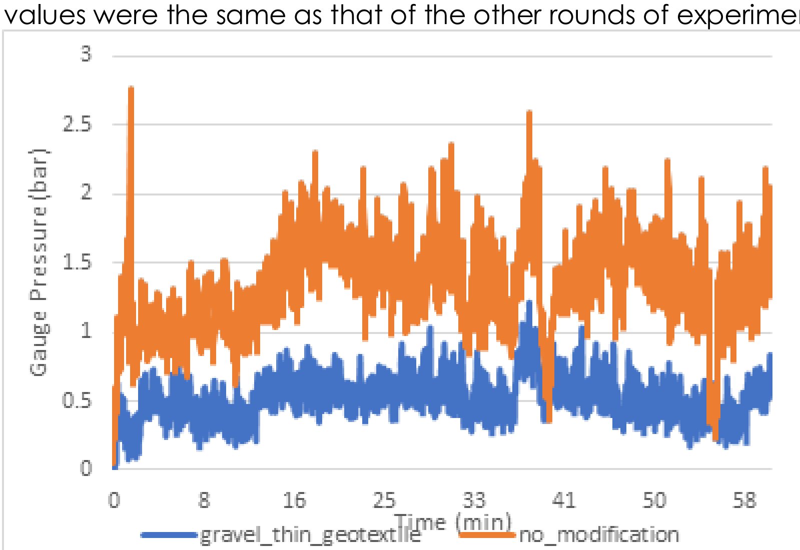


FIGURE 7 PRESSURE HISTORY IN STEADY FLOW RATE EXPERIMENT WITH HIGHER OVERBURDEN HEIGHT

3.2 Assessment of Heat Dissipation

The diffusion coefficient can be approximated using the Einstein's approximation equation. A value of $D = 1 * 10^{-5} m^2.min^{-1}$ is derived. Note that this value is an approximation, and should be considered as such; however, it gives a sense of the order of magnitude of the heat diffusivity in the sand. There are considerable challenges and limitations to develop a numerical simulation of on-site welding activities, as it depends on the welding practice, thickness of plate, shape of weld, etc. For those reasons, it is worth considering monitoring temperature of sand around the PVC pipes with suspected high risk of exceeding allowable temperature. The use of embedded thermal logger is at the level of top of pipe is suggested.

4 CONCLUSIONS & RECOMMENDATIONS

Based on the data presented in Section 3.1, the following can be concluded:

1. Flow resistance provided by the compacted sand was detected in the no_modification state, for both 95 % and 98 % compaction states;
2. There was no detectable significance difference between the 95 % and 98 % compaction state for the no_modification state;
3. The increased overburden has an effect on the pressure buildup. However, the gravel_thin_geotextile (gravel and non-woven polypropylene) filter was effective at dissipating the pressure at desired flow rate;
4. All 3 alternatives were proved to improve the flow of the slurry, for the 95 % compaction state at least, as observed by the negligible pressure build up, which variability can be considered as experimental noise;
5. The gravel and thin non-woven polypropylene geotextile filter has proven to be effective at dissipating pressure in both compaction states tested;
6. No difference was detected between the two geotextiles used; and
7. Considering the 3 alternatives explored, and when it comes to flow improvement, no preferred alternative can be selected.

The following is recommended:

1. Use of filters similar to the gravel_thin_geotextile for improving fluid dispersion
2. Monitor temperature build up at the PVC pipes using embedded thermal loggers

APPENDIX

Soil analysis report

مختبر علوم التربة لفحص المواد

GEOSCIENCE TESTING LABORATORY

REPORT ON DRY DENSITY/ MOISTURE CONTENT RELATIONSHIP

Report No.	: R1DX20-158482
Request No.	: Q1DX20-103424
Senders Ref. No.	: Not Given
Project Name	: Internal Quality Checking
Client Name	: GTC
Consultant	: GTC
Contractor	: GTC
Address	: Dubai, U.A.E
Sampled By	: GTC
Sample Brought By	: GTC

Date: 12/11/2020
Sample No.: S1DX20-103424
Project No.: IQC

Sampling Date: 08/11/2020
Received Date: 08/11/2020

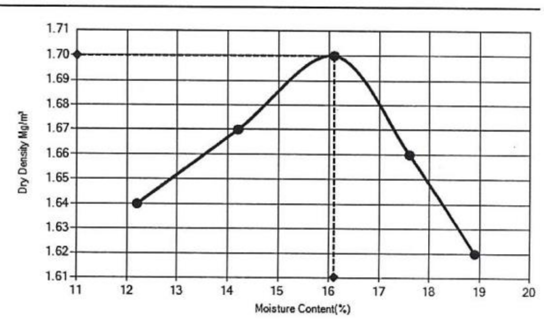
Location	: Not Given
Layer	: Not Given
Source	: Site
Sample Description	: Dune Sand

Sample Size (kg): 50
Lot Size (m³): Not Given
Lot No.: Not Given

Assumed Particle Density (Mg/m³)	: 2.60
Retained on 37.5 / 20 mm (%)	: Nil/Nil

Maximum Dry Density (Mg/m³) : 1.70

Optimum Moisture Content (%) : 16



Date of Testing	: 09/11/2020
Sample Report No.	: Not Given
Sampling Method	: Not Given
Initial Sample Preperation	: #BS 1377 Part 1 : 2016 Cls 8.3 & 8.6
Test Specimen Preperation	: BS 1377 Part 4 : 1990 Cls 3.2.6.1 AMD 8259 : 1995 ; AMD 13925 : 2002
Test Method	: BS 1377 Part 4 :1990 Cls 3.5.4.2 AMD 8259 : 1995 ; AMD 13925 : 2002
Test Method Variation	: None
Tested By	: AUN
Remarks	: #This test is not included in the scope of accreditation by EIAC 003-LB-TEST.

GEOSCIENCE TESTING LABORATORY L.L.C. Plot No. 531-519 Dubai Industrial City Tel.. 04 431 4690 Fax: 04 431 4570 P.O.Box 61670, Dubai, UAE

Suresh S Nair
Technical Supervisor
Dubai

* Results relates only to the items tested.
* Reports shall not be reproduced (except in full) without written approval of the laboratory

Form No: MD/PS-31 Issue:01/22.11.2009 Rev.: 01/19.02.2017

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For GEOSCIENCE TESTING LABORATORY

eiac 003-LB-TEST

Dubai : P.O. Box : 61670, Tel : +971-4-431 4690, Fax : +971-4-431 4570
Website : www.geoscience.ae E-mail : info@gtl.ae

مخـــتـــبر عـــلـــوم الـــتربـــة لفحص المـــواد

GEOSCIENCE TESTING LABORATORY

REPORT ON PARTICLE SIZE DISTRIBUTION

Report No. : R1DX20-158483
Request No. : Q1DX20-103424
Sender's Ref. : Not Given
Project Name : Internal Quality Checking
Client Name : GTC
Consultant : GTC
Contractor : GTC
Address : Dubai, U.A.E
Sampled by : GTC
Sample brought in by : GTC

Date: 12/11/2020
Sample No.: S1DX20-103424
Project No.: IQC

Date of Sampling: 08/11/2020
Sample Received Date: 08/11/2020

Location : Not Given
Layer : Not Given
Source : Site
Sample Description : Dune Sand

Sample Size(kg) : 50
Lot Size(m^3) : Not Given
Lot No : Not Given

Results

Test Sieve Size (mm)	Total Passing (%)
5.00	100
2.00	100
0.600	100
0.425	100
0.300	99
0.150	86
0.075	4
0.063	1

Testing Date : 10/11/2020
Sampling Report No. : Not Given
Sampling Method : Not Given
Initial sample preparation : # BS 1377 PART 1 : 2016 Cls 8.3 & 8.4.5
Test specimen preparation : BS 1377 Part 2 : 1990 Cls 9.2.3 AMD 9027 - 96
Test method : BS 1377 Part 2 : 1990 Cls 9.2.4 AMD 9027 - 96
Test method variation : None
Tested by : AUN
Remarks : #This test is not included in the scope of accreditation by EIAC 003-LB-TEST.

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Form No: MD/PS-32 Issue: 02/12.10.2009 Rev.: 01/19.02.2017
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GEOSCIENCE TESTING LABORATORY L.L.C. Plot No. 531-519 Dubai Industrial City Tel.. 04 431 4690 Fax: 04 431 4570 P.O. Box: 61670, Dubai, UAE

Suresh S Nair
Technical Supervisor
Dubai

For GEOSCIENCE TESTING LABORATORY

eiac 003-LB-TEST

Dubai : P.O. Box : 61670, Tel : +971-4-431 4690, Fax : +971-4-431 4570
Website : www.geoscience.ae E-mail : info@gtl.ae

مختبر علوم التربة لفحص المواد
GEOSCIENCE TESTING LABORATORY

REPORT ON
MOISTURE CONTENT IN SOIL

Report No.	: R1DX20-158484	Date	: 12/11/2020
Request No.	: Q1DX20-103424	Sample No.	: S1DX20-103424
Sender's Ref.	: Not Given	Project No.	: IQC
Project Name	: Internal Quality Checking		
Client Name	: GTC		
Consultant	: GTC		
Contractor	: GTC		
Address	: Dubai ,UAE		
Sampled by	: GTC	Date of sampling	: 08/11/2020
Sample Brought by	: GTC	Sample Received Date	: 08/11/2020
Location	: Not Given		
Layer	: Not Given	Sample size (kg)	: 50
Source	: Site	Lot size (m^3)	: Not Given
Sample Description	: Dune Sand	Lot No.	: Not Given

Results

Moisture Content, %	0.6

Testing Date	: 08/11/2020
Sampling Method	: Not Given
Sampling Report No.	: Not Given
Initial Sample Preparation	: BS 1377 Part 1 : 2016 Cls: 8.3 & 8.4.2
Test Specimen Preparation	: BS 1377 Part 2 : 1990 Cls: 3.2 AMD 9027 : 1996
Test Method	: BS 1377 Part 2 : 1990 Cls: 3.2 AMD 9027 : 1996
Test Method Variation	: None
Tested by	: AUN
Remarks	: None

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GEOSCIENCE TESTING LABORATORY L.L.C.
Plot No. 531-519
Dubai Industrial City
Tel.. 04 431 4690
Fax: 04 431 4570
P.O.Box: 61670, Dubai, UAE

Suresh S Nair
Technical Supervisor
Dubai

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For GEOSCIENCE TESTING LABORATORY

Dubai : P.O. Box : 61670, Tel : +971-4-431 4690, Fax : +971-4-431 4570
Sharjah (Khorfakhan) : P.O. Box : 64800, Tel : +971-9-238 9824, Fax : +971-9-238 9826
Website : www.geoscience.ae E-mail : info@gtl.ae