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Whitechapel Grout Shaft
Thermal Reponse Test
Crossrail

[redacted]

Site Address	Crossrail,, BBMV JV, Whitechapel Main Compound, Cambridge Heath Road, Whitechapel, London, E1 5SD			
Status	Written By	Date	Approved By	Date
Original	[redacted]	20.11.14	DRAFT	

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Appendix 1 Thermal Output

Feasibility Study of Installation of Ground Source Loops Installed in Tube a' Manchette Pipes at Whitechapel Grout Shaft and Thermal Response Test Results

1.0 Introduction

GI Energy (GI) has been commissioned by Crossrail Sustainability Division, to assess the feasibility of installing ground source loops into a series of Tube a' Manchette (TAM) compensation grout pipes which radiate horizontally out of the Whitechapel Grout Shaft. Assuming the installation is possible it is proposed to backfill the grout shaft with a phase change material, or other heat recovery material, and use the loops installed within the TAMs to transfer heat energy from the ground to an adjacent commercial building via a heat pump.

If the conceptual model is feasible and the installation is cost effective, other similar grout shafts will be considered for similar installations.

2.0 Site Location and Grout Shaft Construction

The Whitechapel Grout Shaft is located within the Crossrail BBMV Main Compound, accessed from Cambridge Heath Road, Whitechapel, London, E1 5SD.

Figures 1, 2 and 3 are extracted from BBMV, CRL Document No:C510-BBM-CGMS D061-5007; WMS: Drilling of Arrays in Grout Shaft 1 at Whitechapel Station for Compensation Grouting and gives and shows the site location and installed layout of the TAMS. This document gives the details of the method of installation of the TAMS.

The grout shaft consists of a 4.5m diameter concrete lined shaft some *26*m in depth. TAMs consist of a series of 88.9mm OD steel tubes with a 4mm wall thickness, arranged in three rows some 0.5m apart, which radiate up to 60m horizontally out from the shaft with a distal separation of some 3m. The TAMS overlay the line of the new tube line and below existing building footprints. Injection ports are arranged at 1.0m centres through which grout is injected in response to settlement movement induced by the construction of the new tunnel.

Figure 1: Site Location Plan

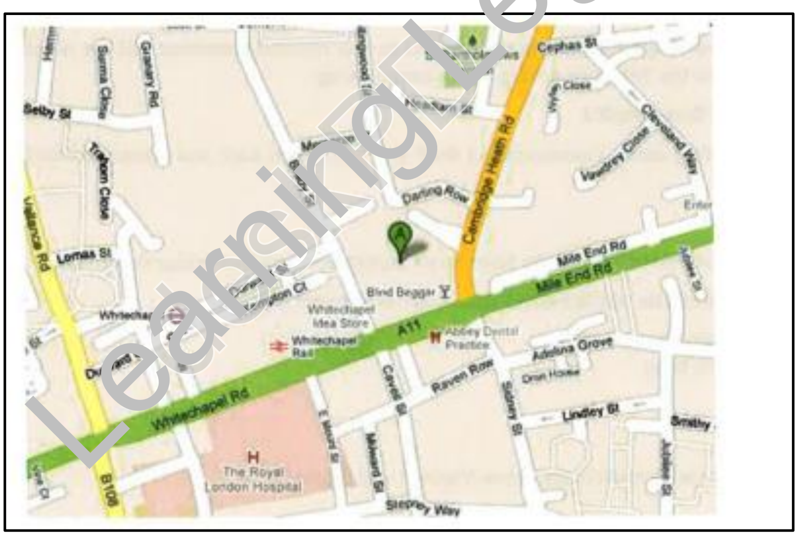


Figure 2: Street Plan Showing Site Location

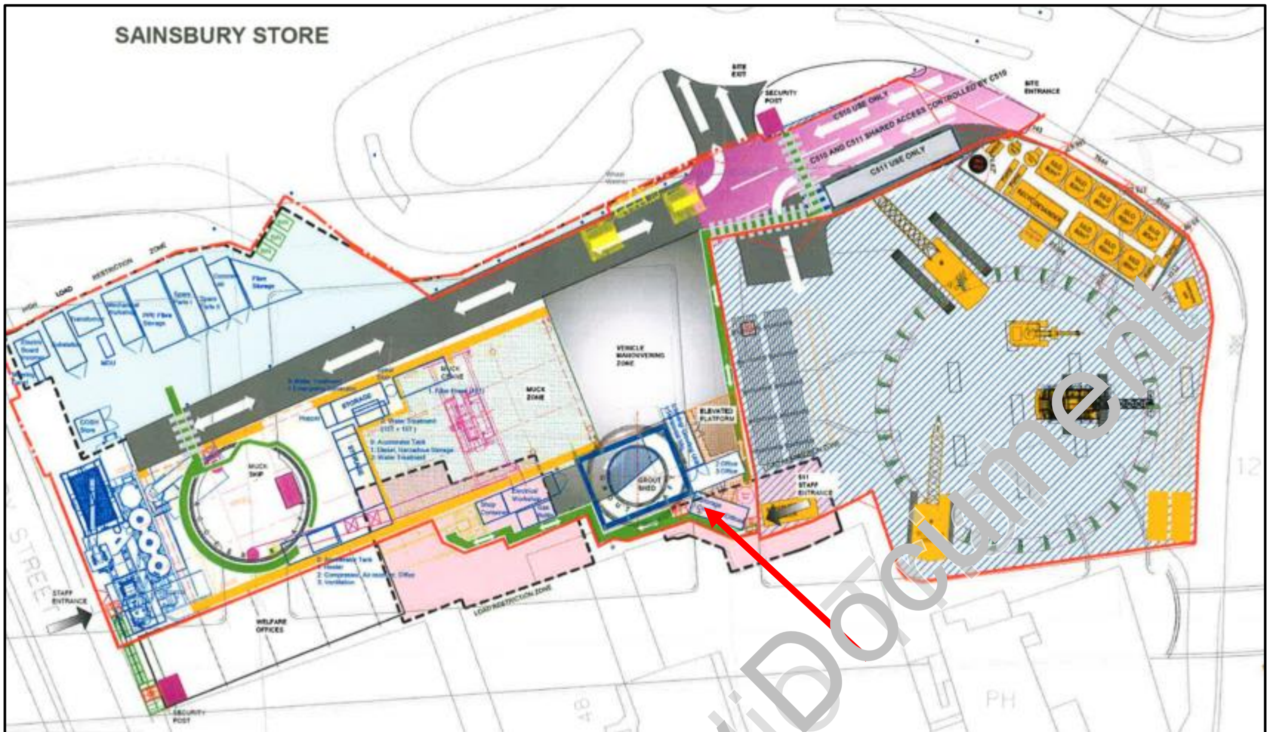


Figure 3: Grout Shaft Location

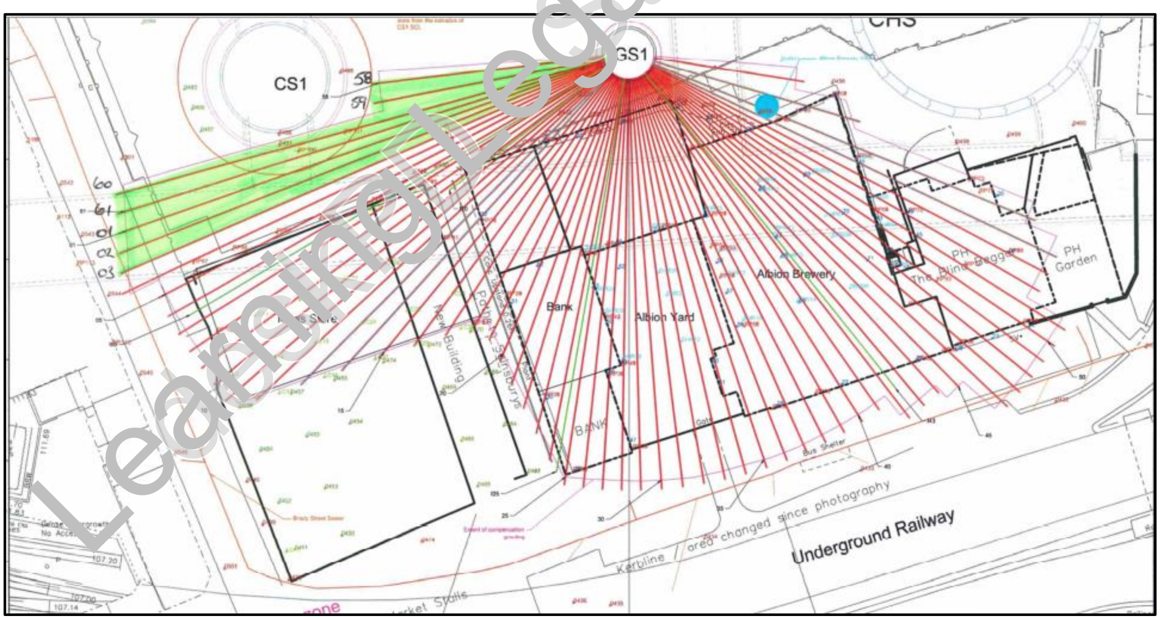


Figure 4: Location of TAMS, green represents TAMS available to GOE for Testing

3.0 Installation of Ground Loops in TAMS

Ground loops consisted of two 25mm OD dia., P100+, HDPE pipe connect with a fused U-bend at the end. Attempts to install two different 32mm dia. loops were made but in both instances the U-bend were too wide to enter the TAMS.

The ground loops were hung vertically on a loop feeder and hand pushed in to the TAMs ref 01, 03 and 60 to their full length, see Figure 5. Little resistance was encountered in installing the loops. A 32mm grout line was installed the full length of the TAMS, and the loop, grout line and a breather pipe were sealed at the mouth of the TAMs with expanding foam.

Once the expanding foam had set the loops were filled with water and flow tested in each directed to ensure there were no obstruction in the loop. They were then hydraulic pressure tested by increasing the pressure in the loop to 8 bars, holding at 8 bar for 30mins, then reducing the pressure to 4 bar and holding at 4 bar for 1 hour.

This was followed by grouting. The grout was mix on site using a hydraulic MAT grout mixer/grout pump and introduce in to the TAM using an extension to the installed grout line.

The first TAM, No 60 , was grouted with a 1:6 enhanced bentonite geothermal grout: sand mix. This is a relatively heavy mix producing an increased in pressure to 20 bar, the normal operating pressure being 4 bar. Only 40m of the 60m TAM was able to be grouted during the first grout run due to the grout feed line pressuring and rupturing. A second short grout line was installed by cutting away part of the expanding foam seal to complete the grouting process.

The second and third TAMs were grouted using a lighter grout mix of 1:5 bentonite:sand using the same method and equipment and installed without issue.

Figure 5: Installation of Loops into the TAMs

4.0 Thermal Response Test

The following gives a generalised description of how a Thermal Reponse Test (TRT) is undertaken. Loops are generally installed in vertically drilled boreholes. In this instance the loops were installed in horizontal drilled holes with a steel liner in to which a 25mm diameter loop was installed and grouted.

Thermal conductivity (k) for soil and rock varies as a function of density and moisture content. Thus knowing the soil / rock type alone is insufficient to determine the thermal conductivity, the single most important element in geothermal ground loop design. In-situ TRT is the most reliable method by which thermal conductivity can be measured accurately. This accurate measurement allows the geothermal designer to avoid over sizing the ground loop to cover potential variations in conductivity on any particular site. The TRT also provides an accurate measurement of the undisturbed ground temperature which is also important to geothermal design.

The concept of the in-situ thermal conductivity testing is to form hole at the location of the proposed ground loop, install an individual loop and grout it, connect a constant heat source to the water being circulated through the loop and measure the energy input and inlet and outlet temperatures. With these values a line source equation model can be applied to the data to determine the thermal conductivity.

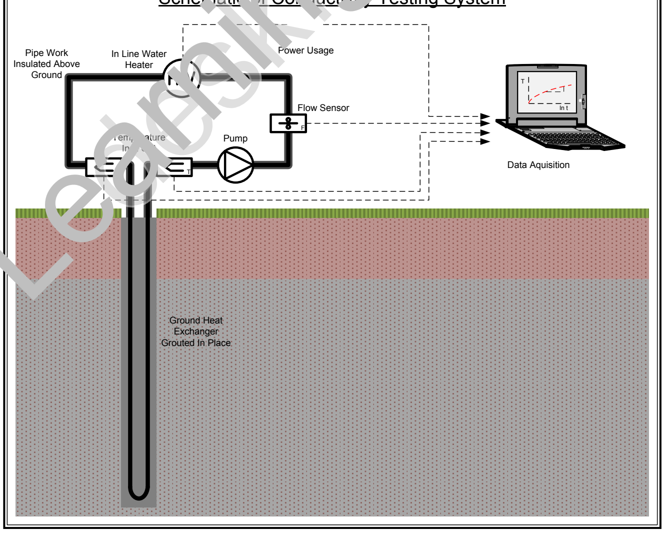
Equipment required for the test is the following,

Ground heat exchanger grouted in place

Constant hot water source
Data acquisition system to measure and record against time,

Temperature In
Temperature Out
Flow Rate
Power Used by Heater

Schematic of Conductivity Testing System



This is housed in an insulated travelling case to protect the equipment during transport and testing.

Test Procedure

The test procedure is as follows,

1 Locate in-situ equipment near completed bore to minimise above ground exposure.

2 Flush loop to remove all debris, cap and set overnight to obtain the most accurate undisturbed ground temperature.

3 Connect ground loop to equipment.

4 Insulate loop leads to reduce temperature bias.

5 Fill in-situ equipment with water.

6 Start data acquisition using good computing practices and with an appropriate recording interval.

7 Turn on the pump and circulate the water for 20 minutes to obtain an average undisturbed ground temperature and to purge any air from the system.

8 Pressurise loop to a static pressure of 70 to 100 kPa.

9 Adjust flow rate to provide turbulent (Reynolds Number > 2,500) and stable flow. As a rule of thumb this is 22 l/min for 32 mm and 34 l/min for 40 mm pipe sizes.

10 Turn on heater to desired power value. Power values range from 40 W to 100 W per meter of pipe installed in bore depending on the anticipated conductivity range.

11 During conductivity testing the following should be monitored,

a Any anomalies in data, e.g. wild fluctuations, very rapid changes or infinite readings.

b Development of minor leaks and any topping up. If large quantities of water are added, the test procedure should be aborted and begun again after the leaks are repaired.

c Electricity supply to the equipment.

12 After the scheduled test duration, typically between 24 to 48 hours depending on the anticipated conductivity, the heaters should then be shut off. With the pump still running, the temperature decay should then be measured for a further test period to establish the heat dissipation properties of the strata. This is a qualitative indication of the diffusivity and is only significant in heat store applications.

13 Shut the pump off and save the data in accordance with good computing practice.

14 The equipment can then be dismantled and removed from site. The bore hole itself can then be used as part of the final installation.

5.0 Test Details and TRT Results

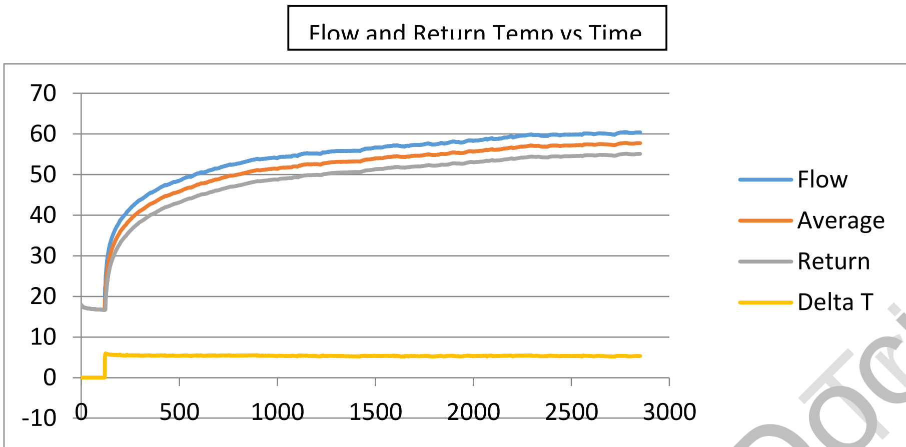
Data has been analysed using the straight line method .The following table summarises the TRT testing undertaken and results obtained:

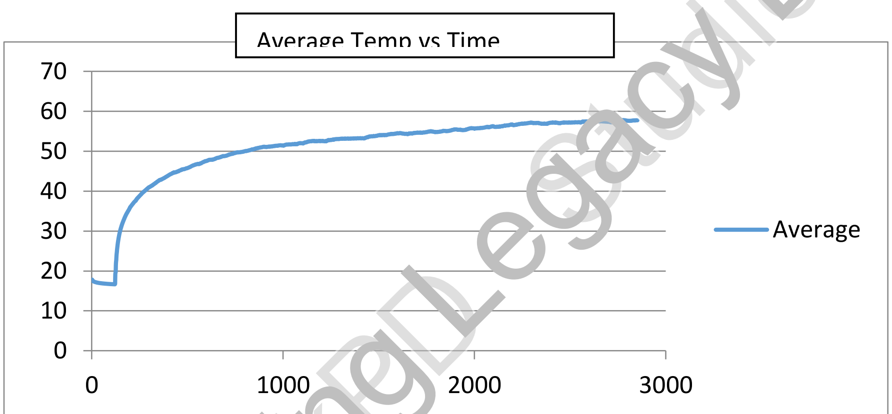
Test No 1	TAM Ref	Test date from and too	Test Duration	No of heat elements	Length of 25mm PE100+ long installed	Grout Mix Sand: Grout	Conductivity $Wm^{-1}sec^{-1}$	Ground Temp °C	Thermal Diffusivity $m2sec^{-1}$
1	60	18/11/14 to 20/11/14	46hrs	2	59	6:1	1.30	16.69	0.82×10^{-6}
2	01	21/11/14 to 24/11/14	80hrs (ran over weekend)	1	[illegible]	5:1	1.40	17.02	0.89×10^{-6}
3	03	27/11/14 to 29/11/14	46hrs	2	59	5:1	1.33	17.03	0.85×10^{-6}

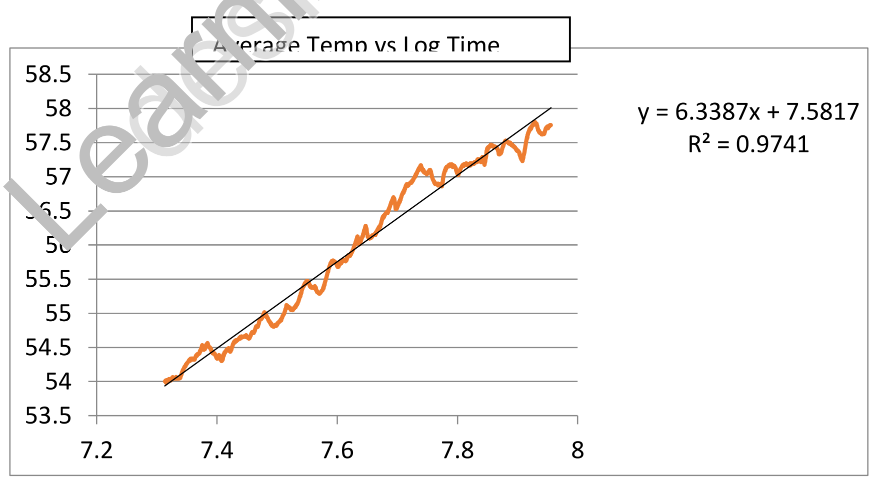
The test data is not as clean as normal due to using a direct main electric power feed the input of which is subject to variation dependent upon the local load demands. Published conductivity values for the London Clay varies between 1.1 and $1.5Wm^{-1}sec^{-1}$ with variation subject to variation in weathering profile and water content. The values produces are consistent and are within the expect range.

Test Results:

Test 1: Tam 60

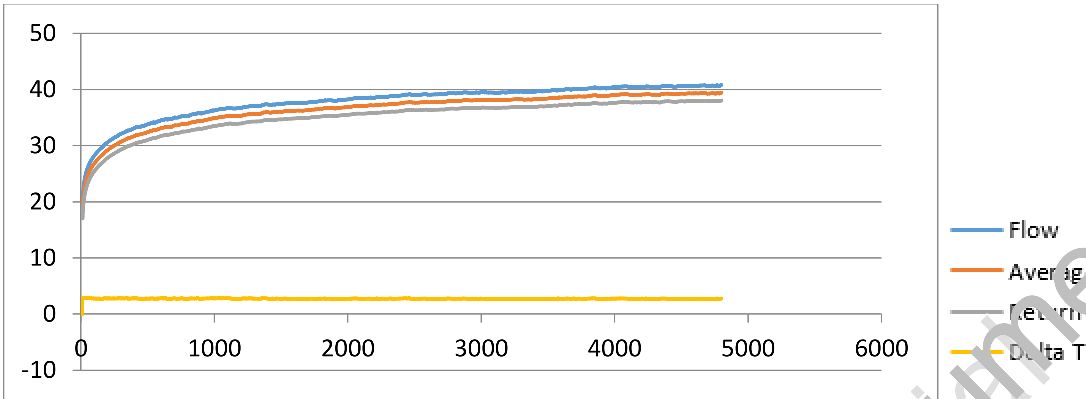




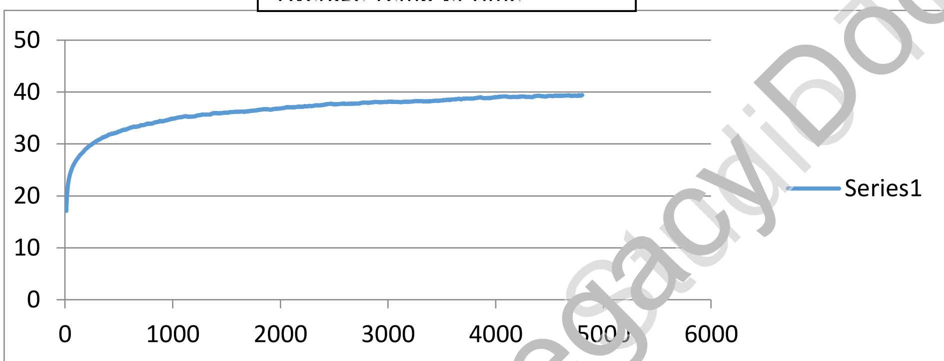


Test 2 TAM 01

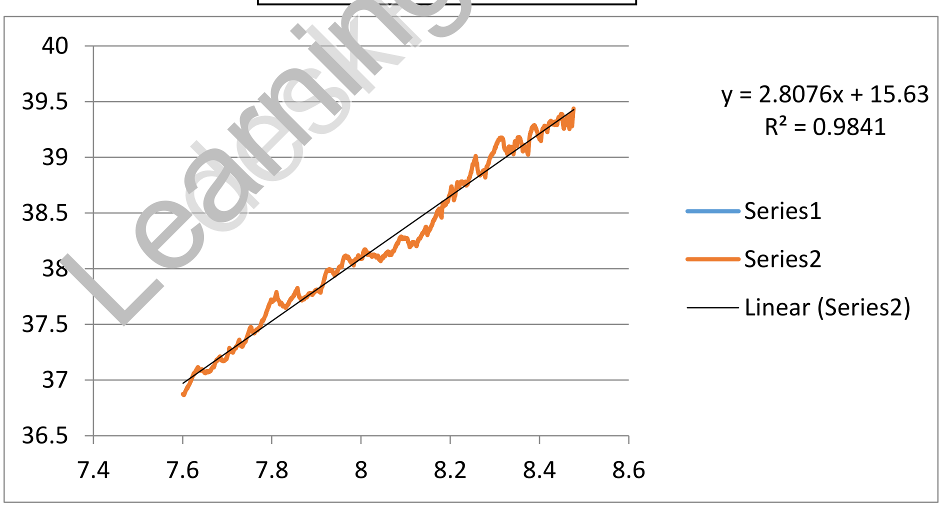
Flow and Return Temp vs Time



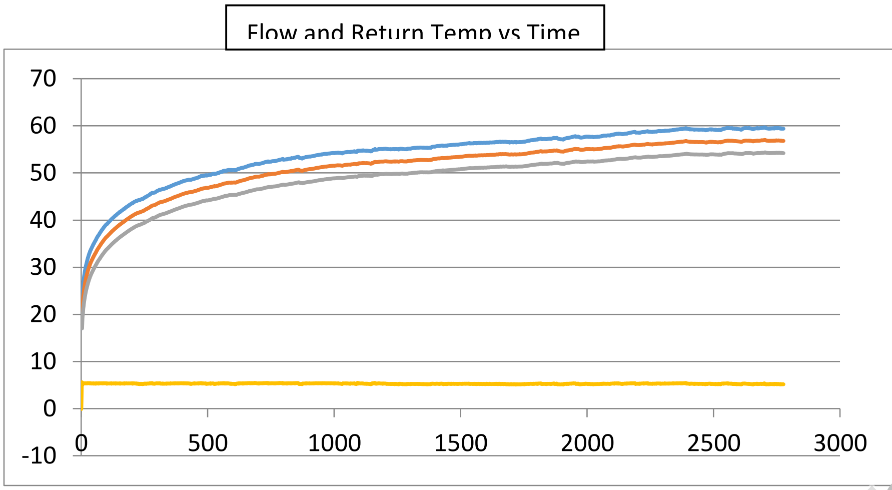
Average Temp vs Time

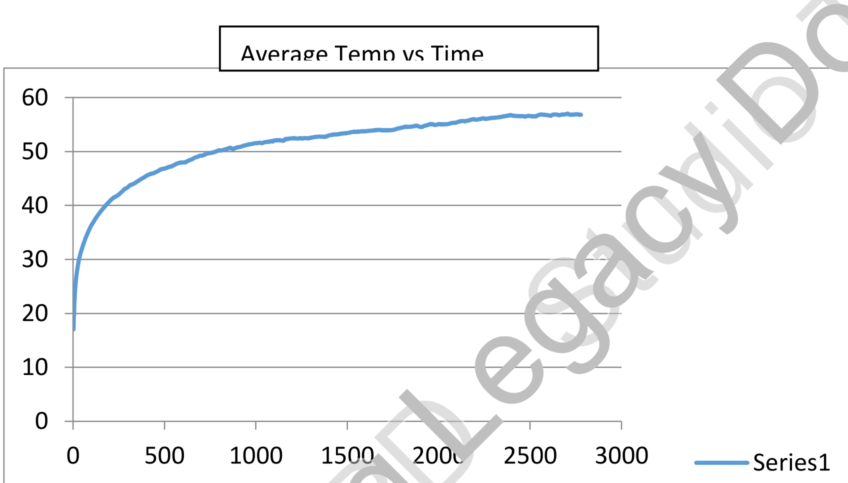


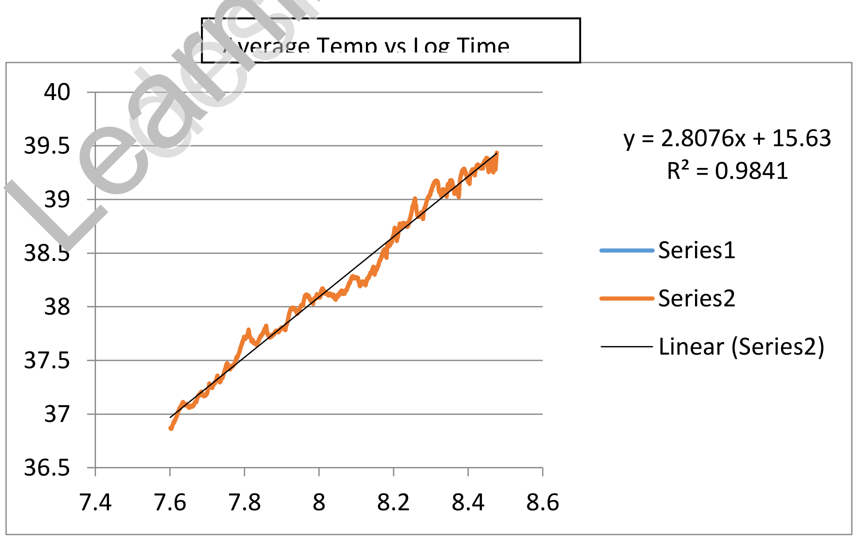
Average Temp vs Log Time



Test 3 TAM 03


Flow and Return Temp vs Time
70
60
50
40
30
20
10
0
-10
0
500
1000
1500
2000
2500
3000
Flow
Average
Return
Delta T


Average Temp vs Time
60
50
40
30
20
10
0
0
500
1000
2500
3000
Series1


40
39.5
39
38
37.5
37
36.5
7.4
7.6
7.8
8
8.2
8.4
8.6
y = 2.8076x + 15.63
R² = 0.9841
Series1
Series2
Linear (Series2)

6.0 Conclusions

We have re-run our conceptual ground loop design using a conductivity value of 1.34kWm^{-1} and ground temperature of 16.91^{o}C using the average values obtained from the TRTs. We have treated the TAMs as a horizontal array to run the analysis the results of which are given in Appendix 1.

The assessment splits the array of TAMs in to arrays and gives an estimate of the total annual heating and cooling loads and total heating and cooling load that can be expected from each array together with an estimate of CO2 and run cost savings.

The exercise has confirmed that it is possible to install and grout in ground source loops into existing TAMS.

Based on our experience for the main installation we would:

I. Consider the use a removal tremmie
II. Blow out water from the TAMS prior to grouting
III. Use the grout mixer and pump at the base of the grout shaft and have extend hydraulic leads to the surface.
IV. Use a bespoke loop reeler to support the loops during installation
V. Use bespoke plugs to seal the TAMs during grouting.

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GI Energy

23.12.14

Appendix 1. – Thermal Output

18/12/2014
GI Ref. 6183 - RevB2

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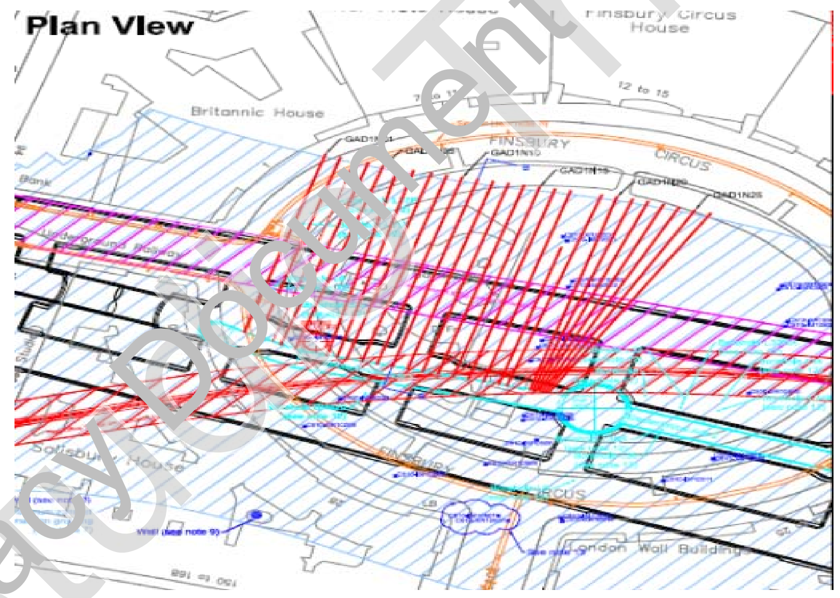
Whitechapel & Liverpool Street Station Tunnels

Summary of Indicative Thermal Outputs from Horizontal Boreholes (TAM's) for Zone GAD1N

Design Data for Zone GAD1N

Number of Boreholes TAM's	Average length of TAM's	Geothermal Loop Diameter (mm)	Diameter of TAM's (mm)
26	54.4	25	89

TAM's Layout for Zone GAD1N



Indicative Heating & Cooling Annual Load Profile Available from Zone GAD1N*

Month	Cooling		Heating	
	Total kWh	Peak kW	Total kWh	Peak kW
January	0		11325	75
February	0		9590	
March	0		7996	
April	195		4861	
May	1399		2393	
June	2823		709	
July	5746	55	256	
August	5687		345	
September	1933		977	
October	214		3261	
November	3		6562	
December	0		11726	
Total	**18,000**		**60,000**	
FLH	**327**		**800**	

Indicative Heating Only Annual Load Profile Available from Zone GAD1N*

Month	Heating	
	Total kWh	Peak kW
January	12457	65
February	10549	
March	8796	
April	5347	
May	2632	
June	780	
July	281	
August	380	
September	1075	
October	3587	
November	7218	
December	12899	
Total	**66,000**	
FLH	**1,015**	

**Outputs based on the averge recorded thermal conductivity of the ground.*

Test No 1	TAM Ref	Test dates of tests	Test Duration	No of heat elements	Meterage Length of 25mm PE100+ long installed	Grout Mix	Conductivity (W/mk)	Ground Temp (oC)
1	60	18/11/14 to 20/11/14	46hrs	2	59	06:01	1.3	16.6[illegible]
2	1	21/11/14 to 24/11/14	80hrs (ran over weekend)	1	59	05:01	1.4	17.02
3	3	27/11/14 to 29/11/14	46hrs	2	59	05:01	1.33	17.03
Average							1.34	16.91

Annual System Savings for Zone GAD1N

Saving	Heating & Cooling	Heating Only
RHI Income (p.a) *	*£ 5,593*	*£ 5,742*
Run Cost Savings (p.a) **	*£ 734*	*£ 498*
CO2 Savings (tons /p.a) ****	*5.5*	*4.0*
Total Annual Savings	*£ 6,327*	*£ 6,240*

Remaining 5No. TAM's Zones at Whitechapel & Liverpool Street

Notes:
*RHI is Based upon 8.7p/kWh for the 1st 1314 FLH, 2.3p/kWh thereafter
Heating savings compared against a gas boiler and cooling savings compared against an ASHP
*** Assumes carbon intensities of 0.206 kg CO2/kWh for gas and 0.591 kg CO2/kWh for Electricity
**Based on 3.08p/kWh for gas with a COP of 0.85 & 9.32p/kWh for Electricity.