# FIELD GEOPHYSICAL INVESTIGATION REPORT
# MARBLE HILL HOUSE

GEOL0020 FIELD GEOPHYSICS PROJECT

LONDON, UNITED KINGDOM

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# 1 ABSTRACT

This report was carried out to investigate the subsurface structure along the terraces of Marble Hill Park House towards the River Thames, using geophysical data obtained from a combination of seismic refraction survey and 1D Vertical Electrical Sounding Survey (VES). A total of 6 receiver line comprising of 12 geophones each at a length of 22m were occupied. Seismic critically refracted data were acquired using the ES-3000/Geode(F) seismometer and processed the data with RadexPro software into 2D velocity depth model using Plus-Minus and Generalized Reciprocal Method (GRM). A two-layer model was delineated by the velocity profile with a range of 400 m/s to 2500 m/s for the entire depth of the probe. In the same line and another line parallel to it around 5-10m away from the initial line, a 1D vertical electrical sounding (VES) using Wenner electrode configuration is surveyed. Resistivity data were acquired using the ABEM LS2 terrameter. The data were smoothened and analyzed using IX1D v.2 software for 1D VES. The aim of this report is to investigate the material and lithology of the subsurface area of Marble Hill house surroundings from upper the terraces down towards the river Thames establishing a geometry and dimensions of the subsurface and also discover if there are any anomalies, for example brick conduit of old drainage system or modern service cable. This was done through taking in field measurements, mathematically manipulate the data to account for errors, and then processing the data.

# 2 INTRODUCTION

## 2.1 HISTORICAL CONTEXT

Marble Hill House and its surrounding grounds form Marble Hill Park; 27 acres of English Heritage Grade II listed parkland in the London Borough of Richmond upon Thames. A number of geological surveys are made throughout the century on the gardens, stretching across the lawn to the south of the house, reaching as far as the north bank of the Thames. Previous geological surveys have hinted at the existence of an old drainage system, running under the garden to the river (Historic England 2017).


*Figure 1 Detail 'Plan of the Parish of Twickenham, Middlesex by W.T Warren', published Isleworth,1846, original scale approximately 1:4790 (British Library Board (Maps 4190. (1) )*

## 2.2 GEOLOGY

The geology of the area is mainly comprised sequences of London clay overlain by superficial, unconsolidated sedimentary deposits of Langley silt or alluvium (Linford et al 2016). The transition in superficial geology from Langley silts to alluvium with increased proximity to the river can be observed. Langley Silts are superficial windblown deposits of loam or silt, commonly found in the south of England. The alluvium forms some of the most recent geological deposits in London, consisting mainly of clay and silt. They mainly occur within river valleys, and are relatively thin, no more than 3m in thickness (Linford et al 2016).

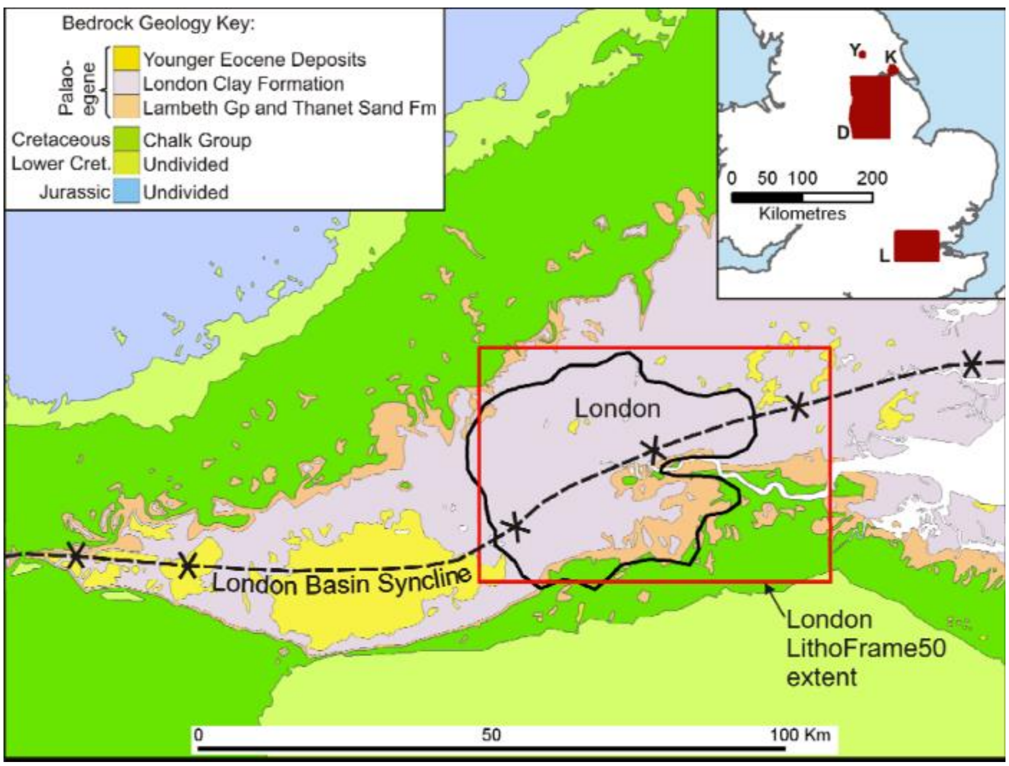


*Figure 2 Summary geological map of the London Basin showing the axial trace of the London Basin Syncline. OS Topography ©Crown Copyright BGS10007897/2009 DiGMap250 BGS ©NERC.*

# 3 LOCATION

Marble Hill Park is located near the East of Twickenham, South West of London. The grounds are border on two sides by the River Thames to the South and also to the East. The specific area of interest is the section of lawn between the river and the house, surrounded by wooded areas to the west and east.


*Figure 3 Marble Hill Park and surrounding areas*

The area of interest is approximately 185m a little bit to the east of the house, with a gradual decrease in elevation towards the river. There are two main drops in elevation around the grotto area. It is said that an old drainage system built with brick conduit is located in the subsurface of the surrounding area of the red line running from the house to the river, and an 18th century culvert (Historic England 2017)


*Figure 4 Area of investigation; Red line*

# 4 GEOPHYSICAL METHODS

## 4.1 GENERAL DESCRIPTION

Two different geophysical methods were used at the Marble House Hill lawn towards River Thames.

- Seismic Refraction
- Vertical Electrical Sounding using Resistivity

A description for each method is given below as it applies to the site.

## 4.2 SEISMIC REFRACTION SURVEY

The seismic refraction method, which benefits from waves travelling in different parts of the underground, is capable of mapping the boundaries between layers characterized by different seismic velocities (Keary, P, Brooks, M and Hill, I 2002). Seismic refraction profiles were performed both forward and reverse shooting techniques. The seismic shot points were located inside the red line site in Fig. 4. Seismic refraction data were analyzed graphically, and P-waves velocities were obtained from slopes of the time-distance graphs. Depths of the layers using travel time equations derived as a function of velocity were computed.

### 4.2.1 SEISMIC REFRACTION (SR) DATA ACQUISITION

The data acquisition equipment consists some of the following units:

1. Energy Source – A hammer blow and a plate, weight drop for generating and transmitting seismic waves into the subsurface. Shot locations points are used every 22m starting from upper terraces hill at 0m until further down the terrace at 132m creating a forward and backward shot profile.
2. Geophones (Receiver) –12 channels of geophones of 2m separation totaling 22m in line are used to detect arrival emanating from subsurface features. The 22m receiver line is used in step until a total length of 132m. The geophones are positioned in the right position using GPS and meter rule.
3. Geophone Cables – to transmit analog electrical impulses from geophones to seismograph.
4. ES-3000/Geode(F) seismometer – Electrical signals are amplified, digitized, and stored in the seismometer's memory.
5. Laptop – to dump field data for data analysis and processing.

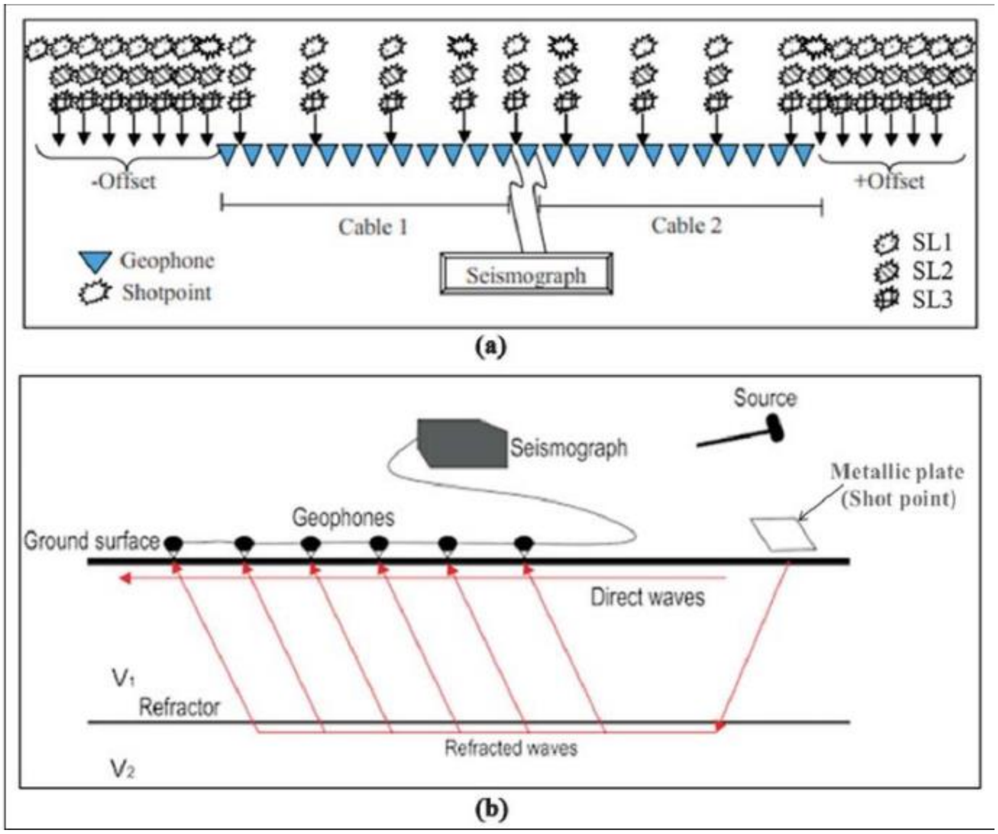


*Figure 5 (a) A typical data acquisition layout showing channel of geophones, geophones' cables connected to seismograph, and location of shot points for every survey line (SL).*

*(b) Instrumentation and progression of seismic waves (P-waves) generated at the surface and refracted at boundary surfaces during data acquisition.*

Figure 5a shows a typical SR data acquisition layout consisting channel of geophones, geophones' cables connected to a seismometer, and a location of shot points for every survey line. Along the offsets, more shot points are required due to the increasing distance between every shot and geophone for high signal-to-noise ratio and deeper depth resolution, unlike shot points that are taken where the geophones are laid (Kearey et al., 2002).

### 4.2.2. SEISMIC REFRACTION DATA PROCESSES

There is many commercially available SR software such as SurfSeis and Res2DInv but in this report I am going to use RadexPro software.

In Radexpro there is built-in feature of seismic refraction data interpretation using the well-known Plus-Minus method in the Easy Refraction module. It covers all processing and interpretation stages – from data loading and geometry assignment to first arrival picking, identification of travel time curve sections corresponding to different layers, and, finally, travel time inversion and generation of a layered velocity model of the medium. The algorithm assumes that the user is already familiar with the theory behind seismic refraction and the Plus-Minus method. Make sure the field data format is readable file format to the software to be used for the data analysis and processing. In this case we are using the SEG2 file (.dat format)

1. After importing all the desired files, check all parameters correctly applied in the system and line up every shot points data file in sequence. In this survey we are using 12 geophones but the tracing in seismograph presented 16 geophones. So, in the software we have to filter out the last 4 traces.
2. First arrival times are manually picked through visual inspection. All picked first arrival times are saved in a new file. Values below the average time are classified to be from the first layer, while those that are higher than the average time are considered to have been refracted from the second layer. One of the geophones (geophone 8) is faulty, so when picking the first-time arrival make sure to properly estimate the arrival time in geophone 7 and 9 and extrapolate both point and to avoid picking error.
3. A travel time curve with each offset shot point locations is generated. Shot points of every 22m is conducted and offset of forward and backward shot points are generated. It is vital to understand which line is forward and backward shot profile.
4. The model is then inverted to produce a 2D initial velocity model using Plus-Minus method and Generalized Reciprocal Method (GRM). Velocity analysis function, composite curve and time depth function graphs are produced for further analyzation.

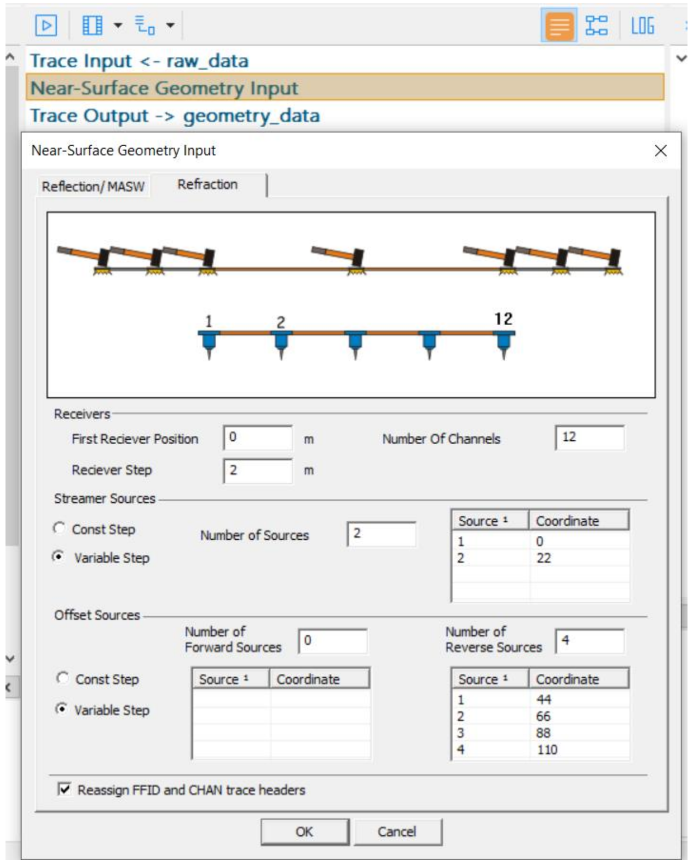


*Figure 6 Near Surface Geometry Input for shot point 0m using the RadexPro*

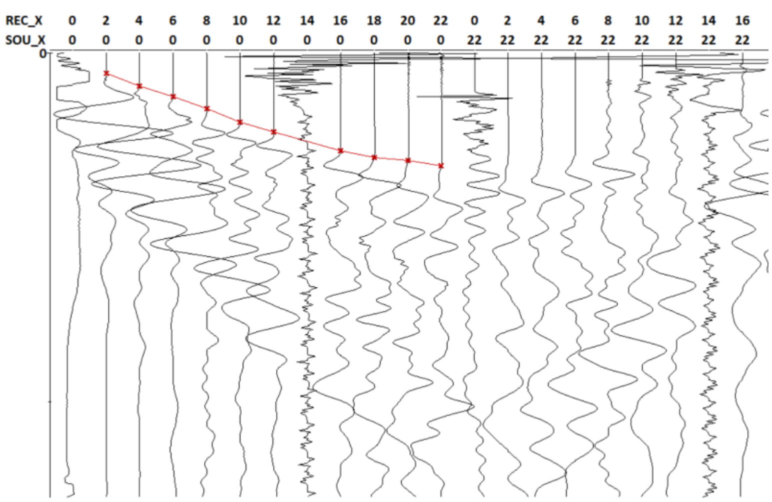


*Figure 7 Picking out First Arrival times using RadexPro. SOU_X is source position and REC_X is receiver position. Geophone 8 is faulty*

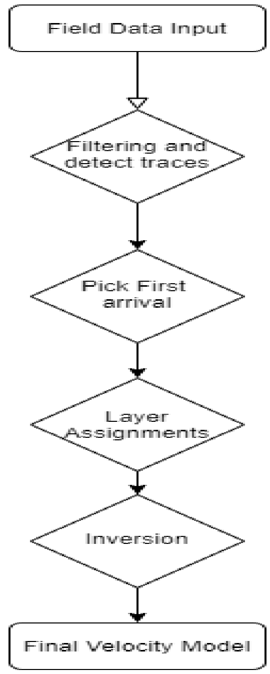


*Figure 8 Basic and simple set up pf Seismic Refraction data processing flow chart*

## 4.3 VERTICAL ELECTRICAL SOUNDING (VES) SURVEY

The resistivity of the ground is measured by sending current into the ground at the current electrodes and the corresponding potential difference is measured at the potential electrodes, which is then converted to apparent resistivity value by multiplying with an appropriate geometrical factor. Different factors affect the resistivity in the subsurface (Telford et al, 1990).

In this survey the VES method are used to investigate the resistivity of the soil in order to figure out its soils' attribute. An analysis is made to interconnect the resistivity with depth to the velocity model of the seismic refraction.

### 4.3.1 VERTICAL ELECTRICAL SOUNDING (VES) SURVEY DATA ACQUISITION

Generally, two potential and two current electrodes are used in electrical resistivity surveys. For this survey Wenner array is deployed. Wenner electrode array is an electrode configuration in which four electrodes are deployed in a line, with equal spacing between the two potential electrodes, and between each current electrode and its nearest potential electrode. All four electrodes move symmetrically about a central point (UCL 2019 Field guide).

The data acquisition equipment consists some of the following units:

1. Instrument: The ABEM LS2 terrameter was used for the field data collection. This instrument measures and displays the resistance of the subsurface. Other instruments used include; metal electrodes, measuring tape, hammer (used in driving the electrodes into the ground), compass, and connecting cables.
2. Technique: The electrode separation (AB/2) varied from 1 to 32 m. Current was passed into the ground through the current electrodes, and the resulting potential was measured through the potential electrodes, and was converted to resistance, which was recorded by the terrameter.

### 4.3.2 VERTICAL ELECTRICAL SOUNDING (VES) SURVEY DATA PROCESS

The resistivity of the soil surrounding the current electrodes were obtained and the apparent resistivity and thickness of the various geo-electric layers were then estimated using IX1D v.2 freeware by Interprex by entering the calculated apparent resistivity and spacing (AB/2) in the new sounding file.

Forward modelling calculations allow the rapid interpretation of field data curves:

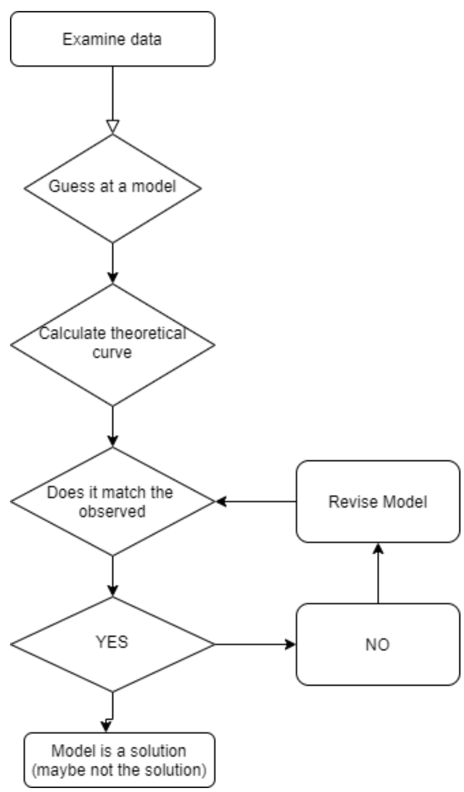


*Figure 9 Flow chart of forward modelling*

# 5 RESULTS

## 5.1 SEISMIC REFRACTION SURVEY RESULT

Seismic refraction was used to determine depth to bedrock layers at the site location where a brick conduit pipeline was said to be lay upon (Historic England 2017). The seismic survey was carried out on the seven traverses shown in the figure 8. From the forward and backward shot profile data gathered during the survey, Time (T) – distance (X) curves were plotted for each traverse. The numbers of line marker segments on these graphs correspond to the number of layers in the subsurface. The reciprocal slopes for these yellow line segments give layer velocities. From figure 10 the slope is consistent suggesting no third layer is derived from the data survey. If a third layer is derived, a slope value ranging from 3000 to 5000 indicating a change to a higher velocity is acquired whilst the data in figure 10 consistently suggesting slope ranging from 1500-2800. Also, data manipulation such as interpolate and mirroring of line segments is used to cover up bad traces of data readings in order to conjured a smooth inversion process.

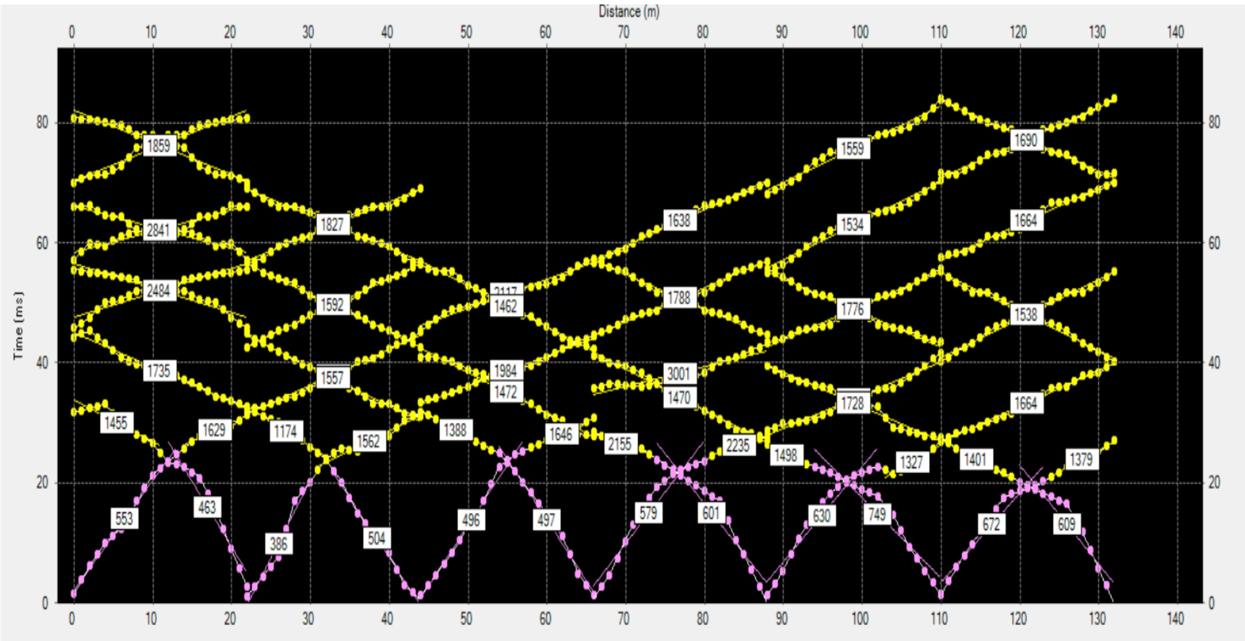


*Figure 10 Time-Distance plot of every offsets shot-point location.*

Note that pink line segments are the direct wave detected by the nearest geophones to shot location and the yellow line segments are the refracted line profile. A very high velocity contrast between the upper and lower layers is highlighted between the pink and yellow line segments by having different slope gradient. This prove that velocity at greater depth (yellow) is greater than unconsolidated upper layer and critical refraction at refractors occurred.

Just for clarification, take one example from one of line segment in figure 10 and show in figure 11. A separation of 2m for the 12 geophones are station at 22m-44m line. Forward and backward shot-points profile are plotted. We can see in figure 11 that the yellow line segments after 22m is backward shot profile while the yellow segment before 22m is forward shot profile. The Pink line, direct wave shot profile was picked up due to closer proximity of shot location to the receiver line. Shot locations at 44m, 66m, 88m, 110m and 132m is recorded as backward shot profile and at 0m is forward shot profile.

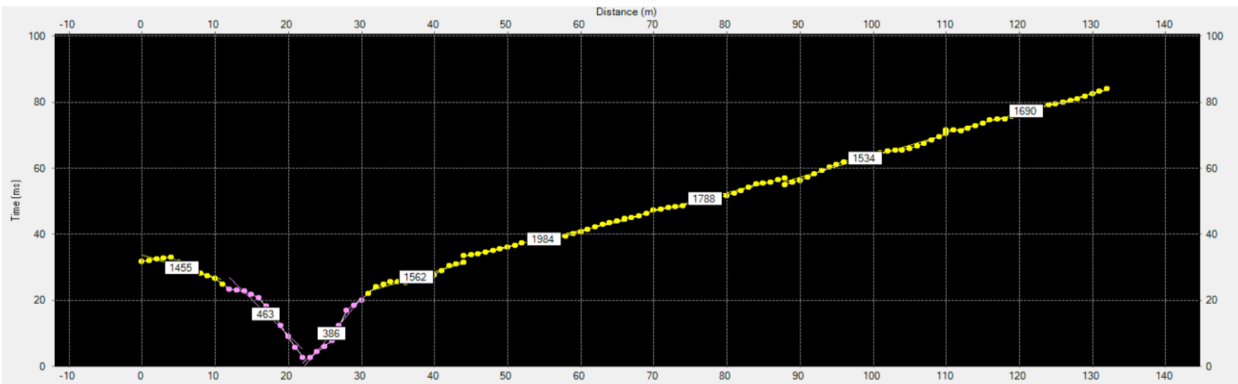


*Figure 11 A line segment of shot point location at 22m with 12 geophone receivers' separation of 2m every 22m with total length of 132m.*

From the T-X plots, the following parameters were derived: layers velocities V1 and V2 and the thicknesses of the overlying layers, Z1 and Z2. Figure 12 gives a summary of the refraction results. 2D velocity-depth model were constructed for each traverse based on the velocities and thicknesses calculated from the T-X curves. The thicknesses were converted into depths by adding up the overlying thicknesses. Using the RadexPro software it automatically uses Plus-Minus method to eliminate the uncertainties of the irregularities of the subsurface layers. Also, Topography corrections are applied in figure 12 by importing the elevation data correction by levelling method in order to resolve the elevation and relief features. Datum is at 0m at depth.

As we can see from figure 12 the first layer has a range of velocities of 400-700 m/s while the second layer has higher velocities range of around 1300-3000 m/s. Complications such as low velocity zone is not apparent in this profile due to V2 larger than V1. For a head wave to propagate, an increase in velocity from one layer to the next is needed. If a decrease in velocity occurs, there will be no head wave and refraction will fail to detect the layer.

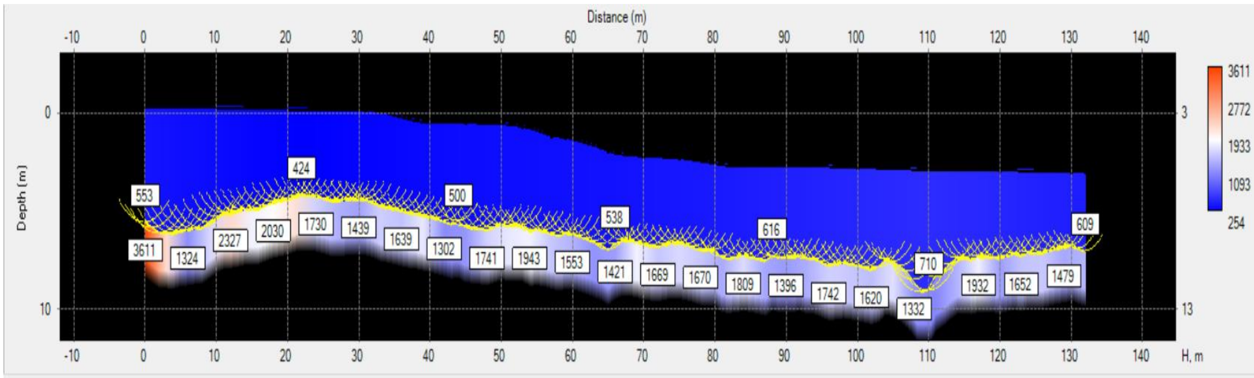


*Figure 12 2D Velocity model profile using GRM and Plus-Minus method.*

Note that the travel times for forward direction, tAD and travel times for reverse direction,t DA are the same. This is a phenomenon are known as reciprocity (Palmer D. 1980). Reciprocal times are total travel times from source location to the last receiver location. The depth of the 2D profile is shallow around 7m in depth. Seismic Refraction survey and plus-minus method are perfect for the survey of shallow subsurface. When the refractor is suspected to have a dip, the velocities of the beds and the dip of the interface can be obtained by shooting a second complementary profile in the opposite direction.

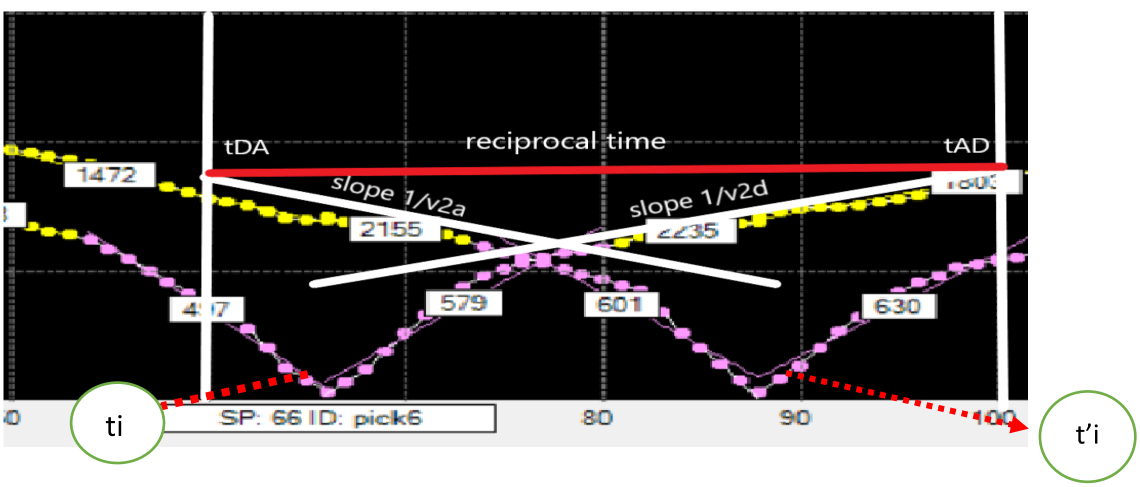


*Figure 13 Reciprocal time for forward and reverse profile using forward and reverse profile.*

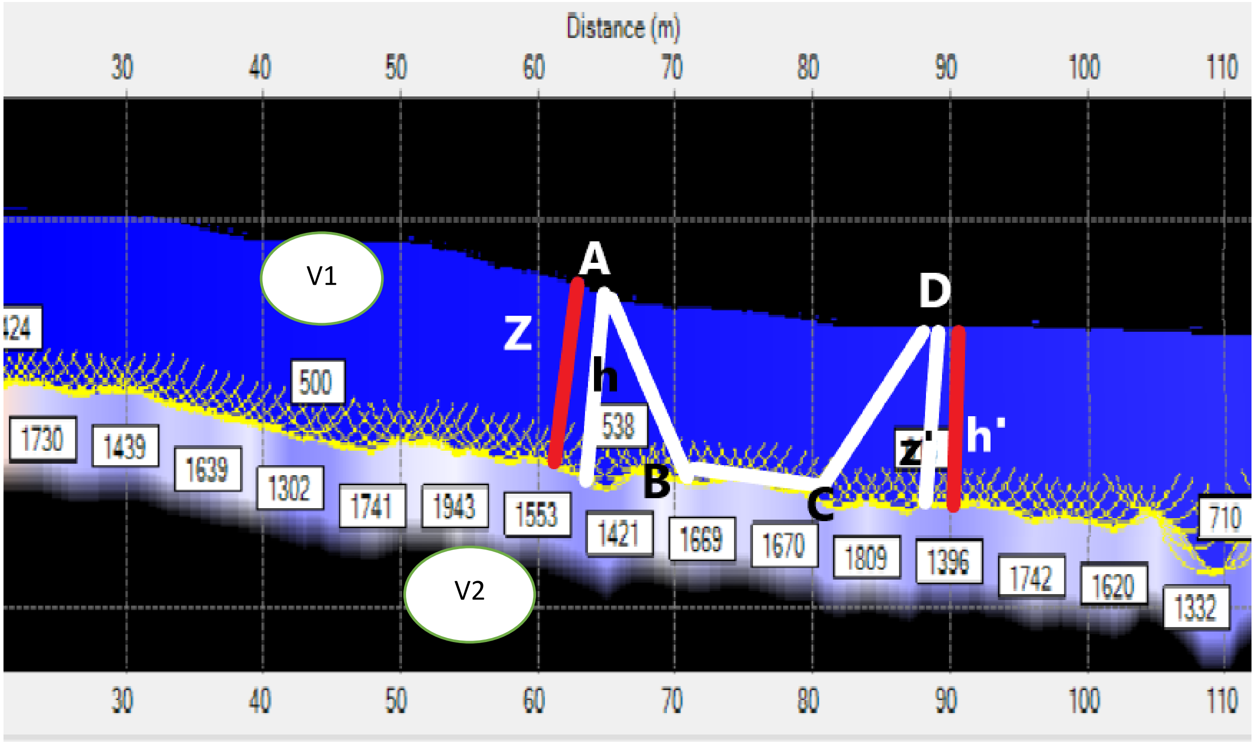


*Figure 14 Dipping layer from shot points 66m and 88m.*

The depths under each end of the survey line (h and h') and two are true velocities. It is obtained from a two-shot (forward and reverse) seismic refraction survey. velocities V1, V2a and V2d, and two intercept times (time to refractor) are measured. These intercepts can be used to calculate z and z' because x=0 when tAD=ti or tDA=ti' and the angle can be found using the three velocities obtainable from the T-X plot. Finally, true depths h and h' can be found using these slant depths and the relation that was found for dip(gamma).

The critical angle ([theta]referred to above) is obtained from the relation involving up-dip and down-dip velocities, and the known value of V1. A less accurate version of V2 can be obtained by averaging V2a and V2d but the average value will be wrong by a factor of cos(gamma), or 2% to 3% for dips of about 12 degrees.

$$\gamma = \frac{1}{2}\left[\sin^{-1}\left(\frac{V_1}{V_{2d}}\right) - \sin^{-1}\left(\frac{V_1}{V_{2u}}\right)\right]$$

$$\theta = \frac{1}{2}\left[\sin^{-1}\left(\frac{V_1}{V_{2d}}\right) + \sin^{-1}\left(\frac{V_1}{V_{2u}}\right)\right].$$

*Figure 15 gamma is the dipping angle and thetha is the angle between refractor and ray parameters.*

## 5.2 VERTICAL ELECTRICAL SOUNDING (VES) SURVEY RESULT

A total number of two VES were carried out, one on the same line as the seismic refraction survey and another one parallel to it around 5-10m east of the line. The results obtained were plotted to get a curve on a graph, with apparent resistivity, (ρa), on the y-axis, and current electrode spacing, (AB/2), on the x-axis.

| Material | Seismic (m/s) | Resistivity (ohm-m) |
|---|---|---|
| Igneous / Metamorphic | | |
| Granite | 4580 - 5800 | $5 \times 10^3 - 10^8$ |
| Weathered granite | 305 - 610 | $1 - 10^2$ |
| Basalt | 5400 - 6400 | $10^3 - 10^6$ |
| Quartz | | $10^3 - 2 \times 10^6$ |
| Marble | | $10^2 - 2.5 \times 10^8$ |
| Schist | | $20 - 10^4$ |
| Sediments | | |
| Sandstone | 1830 - 3970 | $8 - 4 \times 10^3$ |
| Conglomerate | | $2 \times 10^3 - 10^4$ |
| Shale | 2750 - 4270 | $20 - 2 \times 10^3$ |
| Limestone | 2140 - 6100 | $50 - 4 \times 10^2$ |
| Unconsolidated sediment | | |
| Clay | 915 - 2750 | 1 – 100 |
| Alluvium | 500 - 2000 | 10 – 800 |
| Marl | | 1 – 70 |
| Clay (wet) | | 20 |
| Groundwater | | |
| Fresh water | 1430 - 1680 | 10 – 100 |
| Salt water | 1460 - 1530 | 0.2 |

*Figure 16 Resistivity and velocity of common rocks (Zainal Abidin, M.H, Saad, R, Ahmad F, et al 2011)*

Before interpret the data for both VES line, study the above diagram.

The higher resistivity readings > 1000Ωm falls within the range of sandstone, shale, and basalt, and the lower resistivity readings of < 100Ωm matches clay, alluvium, and weathered granite. From figure 12 the first layer velocities comprise velocities ranging from 400-600 m/s and the second layer comprise velocities ranging from 1500-3000 m/s. For the first layer we can deduce that the most of the material falls in the unconsolidated sediment of alluvium. This is particular true for the area near the river Thames because alluvium is loose, unconsolidated soil or sediment that has been eroded, reshaped by water in some form, and redeposited in a non-marine setting For the second layer materials such as sandstone, shale or limestone could be located in the are in particular the upper terraces where little to no contact to the river but also clay sediments could fill the layer below alluvium as such that the seismic waves have to travel longer than in alluvium.

### 5.2.1 GEO-ELECTRIC SECTION TRENDING LINE 1.

The section reveals the presence of three layers. The resistivity of the first layer ranges around 800 ohm-m while its thickness varies from 0.1 m to 0.6m, this could be alluvium due to its high resistivity. This layer constitutes the topsoil. Underlying this topsoil is a sediment which has a resistivity of 800 to 1000 ohm-m, and a thickness of 0.6m – 9m. This sediment could be sandstone, shale, and basalt, may overlie the fresh bedrock.

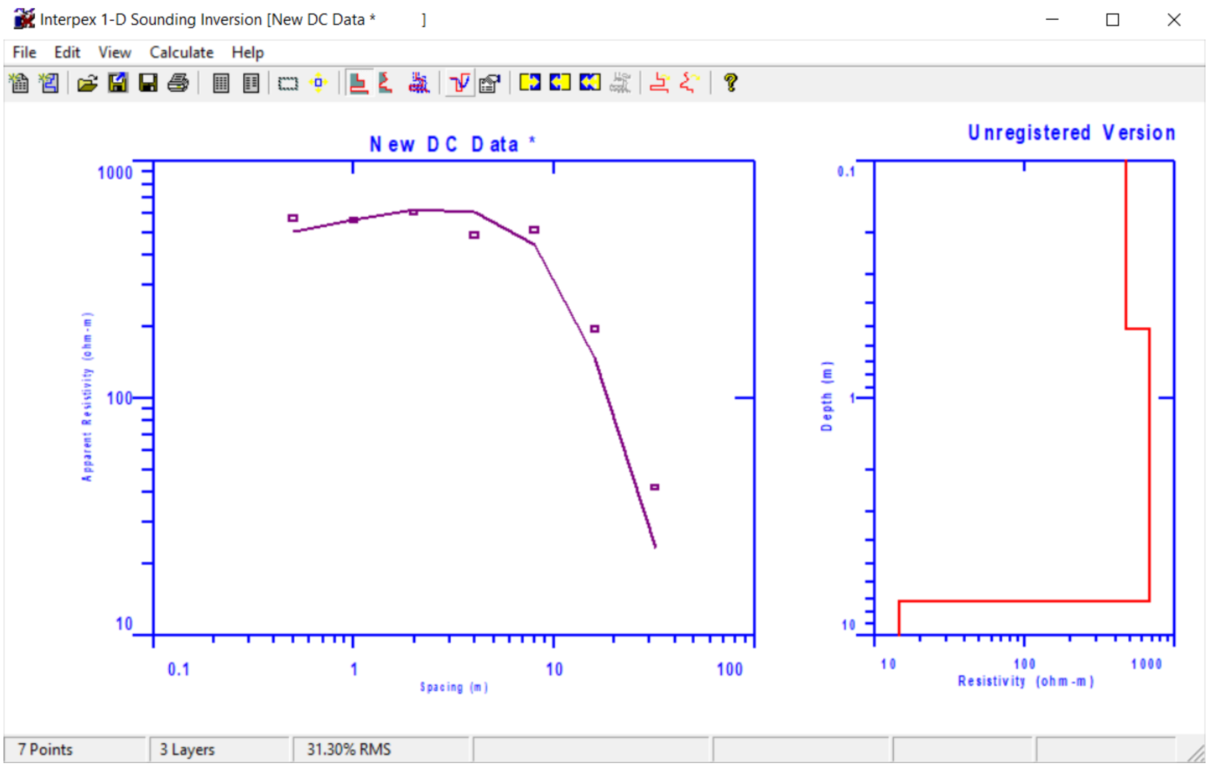


*Figure 17 VES line occupied in the red line in figure 4*

### 5.2.2 GEO-ELECTRIC SECTION TRENDING LINE 2.

The section reveals the presence of three layers. The resistivity of the first layer is much lower than line 1 ranges around 550 ohm-m while its thickness varies from 0.1 m to 0.8m but it is still in the range of alluvium resistivity and it has higher probability of being true due to its location near a river. Underlying this topsoil is a sandy clay layer which has a resistivity of 600 to 900 ohm-m, and a thickness of 0.6m – 9m. Also, falls into range of sediments of either sandstone, shale, and basalt.

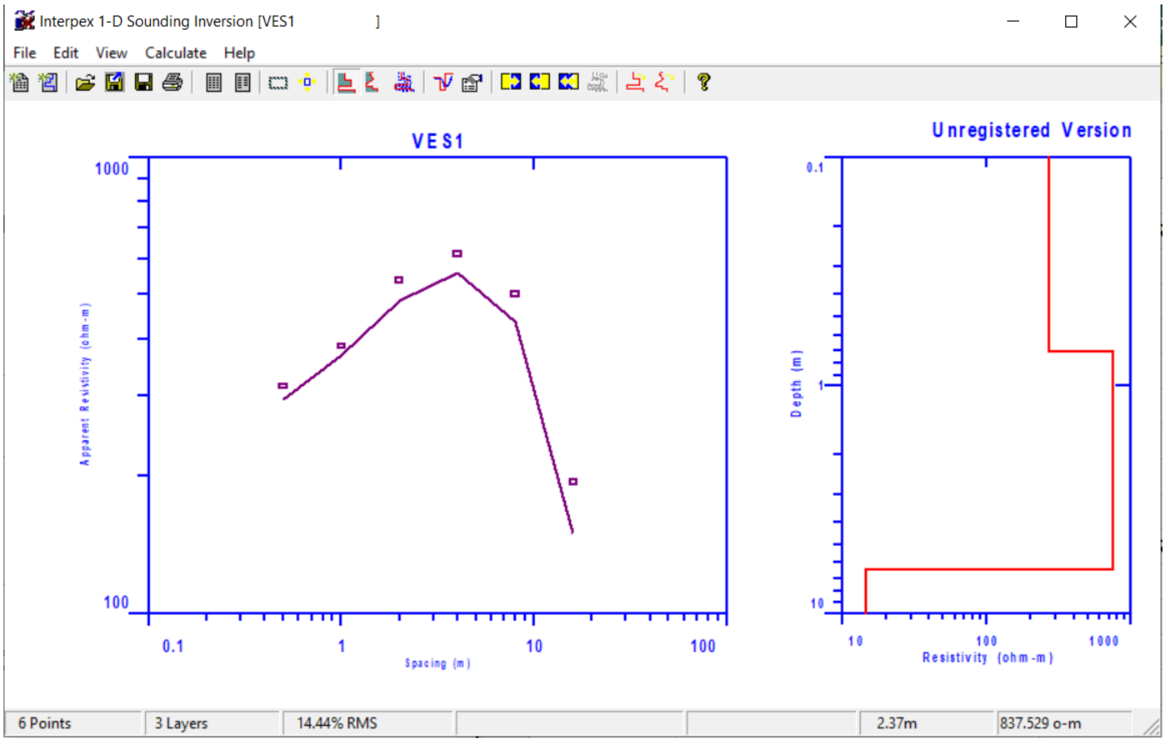


*Figure 18 VES line occupied parallel to line 1 to the east about 5-10m away.*

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Figure 21 is an ERT survey graph taken from previous group of Henrys' 2019 and I have their consent to use the data below. As we can see at the third profile the resistivity is relatively low to the one at high terraces and it shows that material such as alluvium could be well located near it.

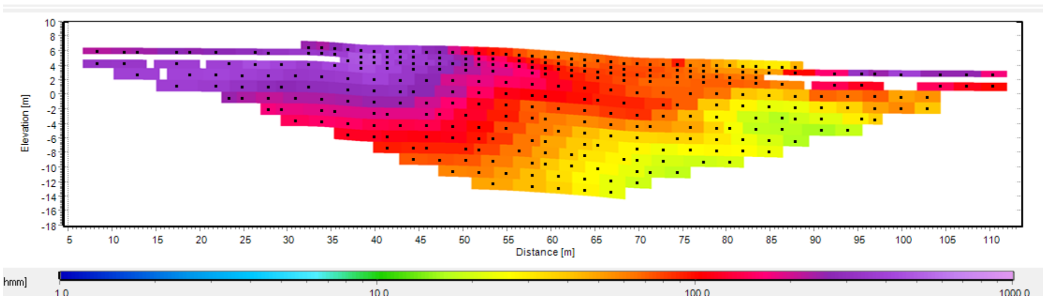


*Figure 19 Electrical Resistivity Tomography survey result done by group Henrietta 2019*

# 6 CONCLUSION

After a lot of data processing to find any anomalies to find a modern cable or brick culvert known to run from the east wing of the house, no data to prove its existence in this report. As stated by a report by Linford et al 2016, the narrow high resistance linear anomaly running SE through the survey area from Marble Hill House towards the Thames corresponds to the line of a known modern service. Parallel to this the survey has detected a brick culvert known to run from the E wing of the house towards the Thames as a high resistance linear anomaly towards the Thames as a high resistance linear anomaly. Both the VES and seismic refraction data are done in the very west of the marble house and could not detect the anomalies.

According to the report by Linford et al 2016, there is a sharp boundary separating a region of higher background resistivity to the North from a region of very low earth resistance approaching the Thames to the South. This may indicate the transition of the superficial geology from Langley Silt to alluvium.

These are very true. From the seismic and VES we could deduce that due to having a lower seismic refraction velocities ranging from 500-700 m/s the first layer could be filled with unconsolidated sediments such as alluvium near the river Thames and sediments such as sandy clay, limestone and sandstone in the upper terraces due to having larger seismic waves penetration ranging from 1500-3000 m/s of velocities and higher resistivities between 800 and 1000 ohm-m.

Recommendation

One way to increase the chance of finding our desired outcome is to acquire multiple data acquisition from every angle of the target site and not just a couple few.

Next, use more than two surveys and more modern data acquisition technology such as Ground Penetrating Radar (GPR) or Magnetometer.

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