Appendix A - Ground Penetrating Radar

Ground Penetrating Radar
Traverses were carried out on a 0.08m parallel grid.

Survey equipment and configuration
Two of the main advantages of radar are its ability to give information of depth as well as work through a variety of surfaces, even in cluttered environments which normally prevent other geophysical techniques being used.

A short pulse of energy is emitted into the ground and echoes are returned from the interfaces between different materials in the ground. The amplitude of these returns depends on the change in velocity of the radar wave as it crosses these interfaces. A measure of these velocities is given by the dielectric constant of that material. The travel times are recorded for each return on the radargram and an approximate conversion made to depth by calculating or assuming an average dielectric constant (see below).

Drier materials such as sand, gravel and rocks, i.e. materials which are less conductive (or more resistant), will permit the survey of deeper sections than wetter materials such as clays which are more conductive (or less resistant). Penetration can be increased by using longer wavelengths (lower frequencies) but at the expense of resolution.

As the antennae emit a "cone" shaped pulse of energy an offset target showing a perpendicular face to the radar wave will be "seen" before the antenna passes over it. A resultant characteristic *diffraction* pattern is thus built up in the shape of a hyperbola. A classic target generating such a diffraction is a pipeline when the antenna is travelling across the line of the pipe. However, it should be pointed out that if the interface between the target and its surrounds does not result in a marked change in velocity then only a weak hyperbola will be seen, if at all.

The Ground Penetrating Impulse Radar used was MALA MIRA High Density Array Radar with antennae frequency 400MHz with the maximum depth of penetration of about 2.5m. Typical depth of penetration for this survey was 1.70m. 0.08m parallel traverses were used to record the data in the area.

Sampling interval
Readings were taken at 0.08m intervals with traverse intervals of 0.08m. All survey traverse positioning was carried out using a Trimble S6 Robotic Total Station.

Depth of scan and resolution
The average velocity of the radar pulse is calculated to be 0.1m/nsec which is typical for the type of sub-soils on the site. With a range setting of 100nsec this equates to a maximum depth of scan of 2m but it must be remembered that this figure could vary by ± 10% or more. A further point worth making is that very shallow features are lost in the strong surface response experienced with this technique.

Calculating the resolution of radar requires highly complex mathematical equations. Research in resolution is an ongoing topic and many experts continue to disagree. As a result some simplification and generalising needs to be done in order to have a useful guide for day to day applications.

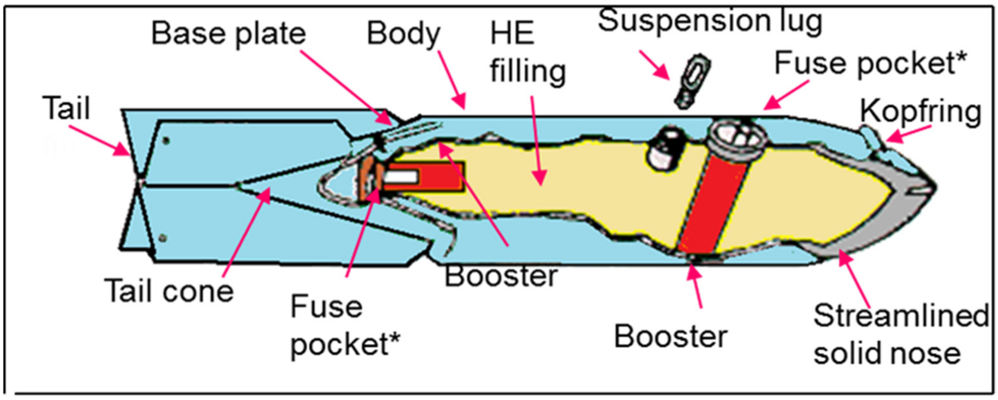
The vertical resolution (ie the ability to distinguish an object which is buried directly below another) is related to the wavelength. Two objects must be vertically separated by a distance equal to or greater than the wavelength to be resolved as two separate features.

The horizontal resolution (ie the ability to detect a single object, or distinguish two objects which are side by side buried at the same depth) is related to the depth of burial. Resolution decreases with greater depth. As a general guide horizontal resolution is approximately 10% of burial depth.

Data capture
Data is displayed on a monitor as well as being recorded onto an internal hard disk. The data is later downloaded into a computer for processing.

Appendix B – Generic German Bomb Types

German bombs dropped during World War II ranged from of 50 kilograms (110 lbs) to 1700 kilograms (3740 lbs) in weight. All of these bombs were fitted with a transverse fuze (sometimes more than one fuse was fitted) although these bombs were dropped many years ago the nature of the explosives after this time has deteriorated to leave it in a very unstable state, liable to cause it to explode. The most common type of German bomb contained HE resulting in blast and fragmentation damage.

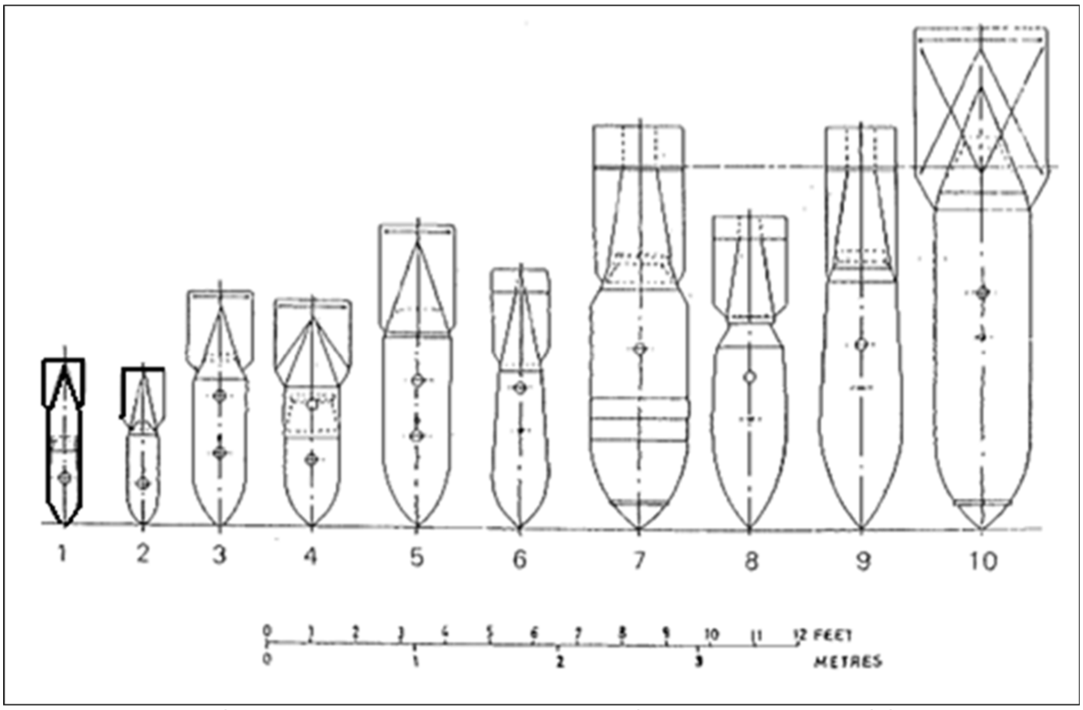


Cross section of a typical 50 kilograms (110 lbs) bomb

Picture of a fuze fitted to German Bombs during WWII

50 kilograms (110 lb) HE
German Bomb

500 kilograms (1102 lb)
HE German Bomb



German High Explosive General Bombardment Bombs - 1=SD 50kilograms. 2=SC 50kilograms. 3=SC 250kilograms.4 = SD 250kilograms. 5 = SC 500kilograms 6 = SD 500kilograms. 7 = SC 1000kilograms (Herman). 8 = SD 1000kilograms (Esau). 9 = SD 1400kilograms (Fritz). 10 = SC 1800kilograms (Satan)

Other types of ordnance dropped were blast bombs/parachute mines and IBs. Blast bombs were relatively thin cased munitions which were designed not to penetrate the ground therefore resulting in major blast damage. In 1940 and 1941 the Luftwaffe used parachute mines against British targets, which were originally designed for use as magnetically-triggered sea mines.

German Parachute Mine

The 1 kilogram (2.20lb) incendiary bomb these bombs were delivered to the target area in containers when initiated the container would open dispersing the smaller incendiary bombs

Over-All Length: 52.7 cm (20.75 inches). Body Length: 23.5 cm (9.25 inches). Body Diameter: 5.1 cm (2.0 inches). Wall Thickness: 2.2 cm (3/8 inch). Tail Length: 12.1 cm (4.75 inches). Tail Width: 5.1 cm (2.0 inches). Total Weight: 2.2 kg. (4.85lb) Type Of Filling: Incendiary--Thermite H.E TNT Weight Of Filling: N/A Charge/Weight Ratio: N/A Fuzing: AZ 8312 B	

Appendix C – Utility

PAS 128 survey defines four types of survey:

i. *Desktop utility records search (Survey Type D) – where underground utilities are identified through the collation and analysis of existing utility records;*
   - *This was executed before the fieldworks.*

ii. *Site reconnaissance (survey type C) – where existing records are supported and validated by the visual inspection of physical evidence observed during a site visit;*
   - *This wasn't requirement of the survey.*

iii. *Detection (survey type B) – where underground utilities are detected and located by the geophysical techniques of EML and GPR;*
   - *This was the main requirement of the survey.*

iv. *Verification (survey type A) – where underground utilities are observed and located at a manhole or inspection chamber, or are excavated and exposed.*
   - *The manhole covers were lifted to provide Quality Level A results. There was no intrusive verification required.*

Type B survey detection methods

i. M1 and M1P – EML orthogonal search transect at ≤10m intervals and when following a utility trace, search transects at ≤5m intervals; GPR use as applicable.
ii. M2 and M2P – EML orthogonal search transect at ≤5m intervals and when following a utility trace, search transects at ≤2m intervals; GPR ≤2m orthogonal grid or high density array.
iii. M3 and M3P – EML orthogonal search transect at ≤2m intervals and when following a utility trace, search transects at ≤1m intervals; GPR ≤1m orthogonal grid or high density array.
iv. M4 and M4P – EML orthogonal search transect at ≤2m intervals and when following a utility trace, search transects at ≤0.5m intervals; GPR ≤0.5m orthogonal grid or high density array.
   NB Suffix P means post processing off site of the GPR data.

The methodology agreed with the client was M4P for the whole area.

General notes

Because of the limitations of the two techniques required by PAS 128 with regard depth of penetration PAS 128 only applies to a depth of three metres.

Electromagnetic Location

Electromagnetic locators currently does not allow for post processing of the data therefore all interpretation is carried out by the surveyor whilst on site.

The use of EML is subdivided into active and passive methodologies. The active element of the work is carried out first where a signal is applied by the surveyor. This is then followed by passive sweeps to detect possible utilities where no active signal could be applied.

Ground Penetrating Radar

Radar transects are collected on a grid pattern at centres determined by the specified methodology.

Where on site interpretation has been specified, the data is recorded but not post processed. The surveyor interrogates each transect at the time of collection to identify the characteristic responses from utilities (known as a point diffractions) and mark their position and depth on the ground surface.

Where post processing interpretation has been specified, the recorded gridded data is transferred to the office where the point diffractions are identified and their positions abstracted onto the base mapping. As point diffractions may be formed by 'clutter' from discrete objects such as stones, their plotting will allow linear patterns such as those formed by utilities to be recognised.

Allocation of quality levels

Where onsite interpretation only has been instructed the surveyor compares the results of EML and GPR in order to allocate a quality level in accordance with the requirements.

Where post processing is carrying out this procedure is completed in the office and transferred onto the base mapping.

Electromagnetic Location

An electromagnetic detection tool will locate "live" power cables by detecting their magnetic field. It cannot however, locate a cable where the power is turned off i.e. street light cable during the day.

Live High Voltage cables can also be "well-balanced" i.e. they create little magnetic field and can therefore be difficult to detect.

The positions of a detected service may be inaccurate up to 400mm to the left or right; this is known as magnetic field offset. Additionally adjacent metal objects e.g. metal fencing can also cause magnetic field offset. Static emissions e.g. overhead power lines, may also cause interference and limit results. Used in signal induction mode to locate metal pipes, telecom cables, power cables, drains & ducts. However blocked drains, pipes or chambers will prevent tracing and limit the results.

Electromagnetic detection will not locate terminated (dead end) cables, non-metallic pipes or inert utilities, such as plastic pipes, fibre optic cables and ducts, clay pipe work, culverts, etc.

Close proximity of utilities can prevent individual service identification. Generally a 250mm horizontal separation is required to achieve this. Where we may not be able to separate individual services, a Multiple Service Route "MSR" or Area of Concern "AOC" may be indicated on the drawing.

The drainage information provided is restricted to cover levels, invert levels (ILs mapping only) and direction of flow, where this information can be ascertained at the time of the survey. Pipe sizes and materials cannot be identified by the technologies and methods used.

Ground Penetrating Radar

GPR devices emit microwaves and their use is regulated by OFCOM. A GPR antenna transmits microwaves into the ground which are reflected back to the unit, which then interprets the results to produce a profile of what is under the ground. A buried service has a different dielectric constant to the surrounding soil, which causes the reflection.

GPR products used for utility detection can generally penetrate the ground up to a depth of 2.5 metres. This depends upon soil conditions and moisture content and the antenna frequency. As a guide, high levels of detection are usually achieved in dry light soils, whereas wet clay soils and saturated ground may prevent accurate results from being attained.

GPR antennas require close to or actual ground contact, ideally over smooth surfaces. Uneven ground, including unmade ground and long grass will impede detection of inert utilities.

Reinforced concrete mesh degrades the signal, prevents depth penetration and may also cause false targets to be indicated. The results from electromagnetic detection are similarly affected.

Results are dependent upon the makeup of the ground and made up ground, multiple backfill layers and dense clay can affect results leading to undetected services.

The survey used Mala MIRA High Density Array Radar with antennae frequency 400MHz.

Appendix D – Seismic Refraction

Line locations
The location of the survey lines has been plotted together with the referencing information. Lines were initially set out using a Trimble R10 RTK GPS for line orientation and individual geophone location using survey tapes between end points. Each individual geophone was then measured with very high accuracy for location and height using a using a robotic total station referenced to a Trimble R10 RTK GPS.

An RTK GPS (Real-time Kinematic Global Positioning System) can locate a point on the ground to a far greater accuracy than a standard GPS unit. A standard GPS suffers from errors created by satellite orbit errors, clock errors and atmospheric interference, resulting in an accuracy of 5m-10m. An RTK system uses a single base station receiver and a number of mobile units. The base station re-broadcasts the phase of the carrier it measured, and the mobile units compare their own phase measurements with those they received from the base station. A SmartNet RTK GPS uses Ordnance Survey's network of over 100 fixed base stations to give an accuracy of around 0.01m. A total station gives a very high accuracy of 1-2mm.

Survey equipment and configuration
The survey was carried out using a Geomatrix 24 channel, 24-bit exploration seismograph used with single component geophones. Layout of the geophones and number of seismic spreads depends on a balance between required penetration depth of survey and resolution of subsurface reflectors, detailed below.

Survey Resolution
Geophones are located at a spacing to gain maximum resolution while still retaining depth penetration required by the survey. The closer the geophone spacing the higher the sample resolution but the lower the depth penetration, typically geophones are spaced between 0.25m and 5m and may be varied during the survey to image specific seismic events with more detail.

Depth penetration of Survey
The depth of penetration of the survey is one fifth of the total spread length, assuming signal to noise ratio remains high all the way to end of line from source. If needed, extra depth penetration can be achieved by undertaking 'offset shots' where the seismic source is placed some distance away from the geophone spread.

Data Capture
The seismic data collection is triggered by the seismic source making contact with the ground and is recorded in the field on a tough book computer. If the signal to noise ratio in the data is low repeated seismic sources on the same line can improve this.

Appendix E – Basic Principles of Seismic Refraction

Seismic waves can be generated in the subsurface using a seismic source, this will generate a number of different wave types but the only type we shall consider here is the primary wave (P-wave). Seismic refraction relies on the generation of 'head waves' on the surfaces of geological layers that have a contrasting seismic p-wave velocity to the layer above. This head wave is only generated at the 'critical angle' between two layers of different velocity, which is equal to:

$$\sin i_c = \frac{v_1}{v_2}$$

Where $i_c =$ Critical angle
$V_1 =$ Seismic velocity of Layer One
$V_2 =$ Seismic velocity of Layer Two

This head wave creates responses from our reflector at depth which is picked up and recorded by geophones (figure B1). These responses are the first seismic arrivals at the geophones, known as 'first breaks', identifying these in the data forms the basis of seismic refraction interpretation. The generation of critical waves will occur in subsequent layers as long as velocity always increases with depth. If velocity decreases from one layer to the next a head wave cannot be generated.

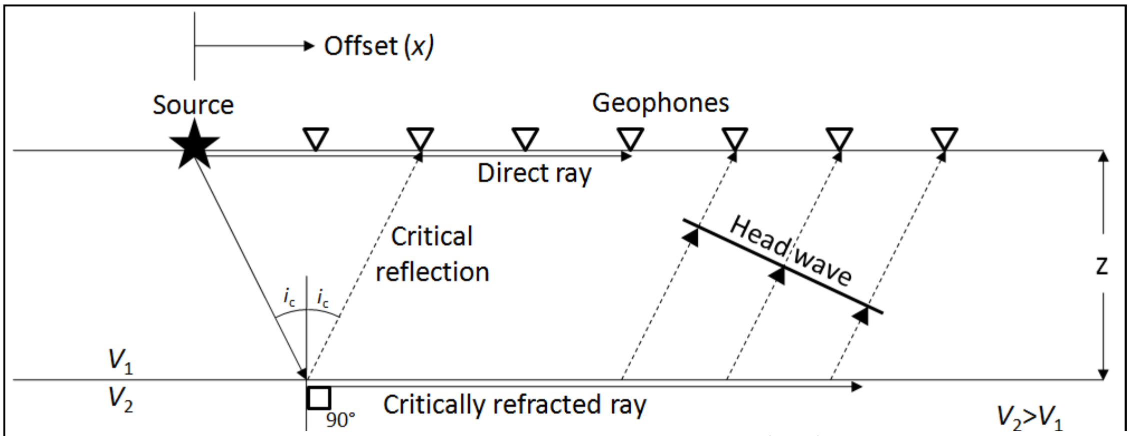


Figure B1. Raypath Diagram showing refractive wave theory. Adapted from Reynolds (2011).

On a time against offset chart first breaks appear as a straight line and the inverse of the gradient of this straight line gives the seismic velocity of this layer. The distance at which the seismic event starts appearing on the time against offset chart is called the critical distance which is related to the depth of the seismic horizon the refracted arrival is coming from. Therefore we can use the velocity of the layer and this critical distance to evaluate the depth of the layer, and we can also make an assumption on its lithology based on the layers velocity.

Where a layer is dipping or undulating in character calculations can become complex but are resolvable; situations in which refraction surveying cannot resolve depths and velocities of layers include:

- Velocity inversion (velocity decreases with depth so a head wave cannot be generated).
- A layer is too thin to be seen by the geophones (can be solved with a decrease in geophone spacing).
- A layer has too small a contrast in velocity in overlying layers to create a response.

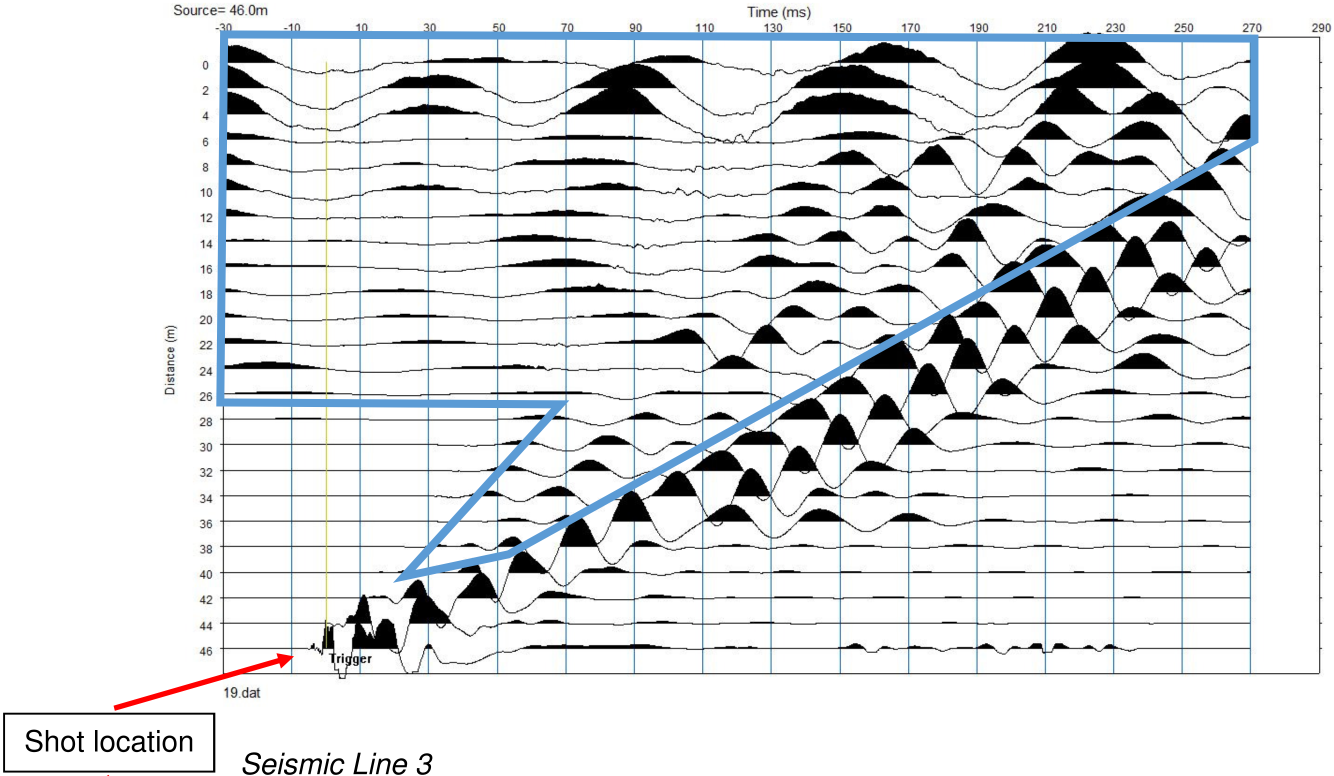
Appendix F – P-Wave Velocities for Various Materials

Adapted from Reynolds (2011)

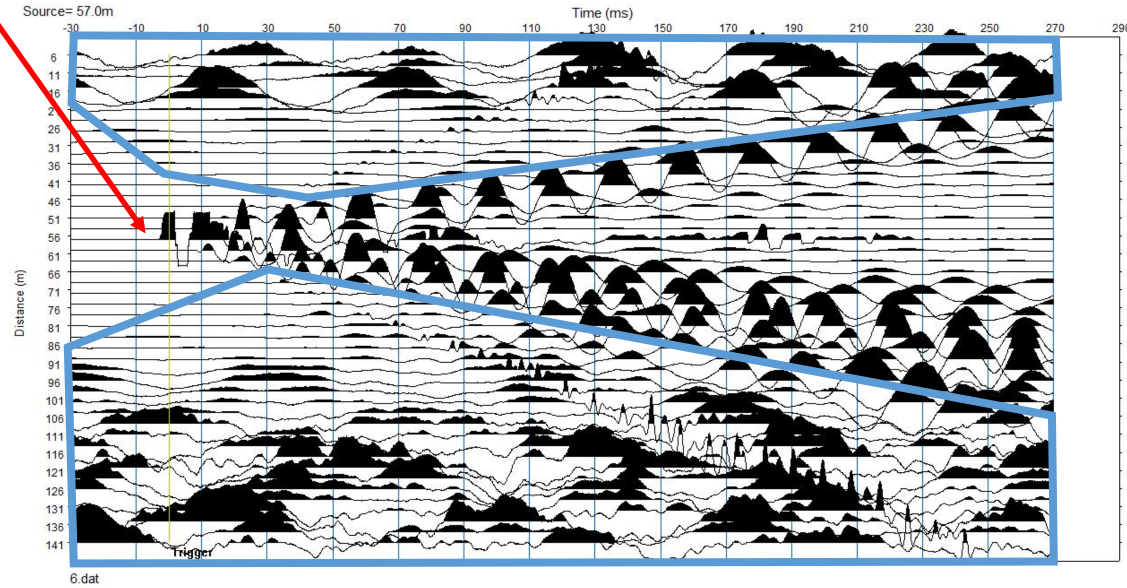
Material	V_p (m/s)
Air	330
Water	1450-1530
Soil	100-500
Loess	300-600
Sand (loose)	200-2000
Sand (dry, loose)	200-1000
Sand (saturated, loose)	1500-2000
Sand and Gravel	400-2300
Clay	1000-2500
Esturine Muds	300-1800
Floodplain Alluvium	1800-2200
Sandstone	1400-4500
Limestone (soft)	1700-4200
Limestone (hard)	2800-7000
Granites	4600-6200
Basalts	5500-6500
Gabbro	6400-7000
Concrete	3000-3500
Disturbed Soil	180-335
Landfill Refuse	400-750
Made Ground	160-600

Appendix G – Raw Seismic Data from Line 1 and Line 3

Seismic Line 1



Seismic Line 3



The areas within the blue lines represent the ‘noise’ present. Line 3 was much noisier than Line 1. Both have had their first arrival times obstructed by the noise, making first picks almost impossible and would render the data unreliable if attempted to model. In good data there should be a clean, clearly visible line of best fit cutting through the first arrival times. This is not observed in these examples.

Appendix H – Resistivity Values for Various Materials

Adapted from Saad et al (2012)

Material	Resistivity (Ωm)
Alluvium	10 to 800
Sand	60 to 1000
Clay	1 to 100
Groundwater (fresh)	10 to 100
Precipitation	30 to 1000
Sea Water	≈ 0.2

Appendix I – Statutory Records Search