Understanding the limits of detectability of unexploded ordnance – do you know what you are paying for?

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Summary

The threat of unexploded ordnance (UXO) including unexploded bombs (UXB) to land developments in some areas of the UK is well known. There are currently no recognised standards in the UK governing the advice provided or service offered to mitigate ordnance risk. As a result anyone can profess to be an expert which has led to clients receiving ambiguous advice on safety critical issues such as the limits of detectability of buried UXO. Exaggerated claims of UXO detection depths for surface surveys or detection radii for probe or drilling based bomb detection methods will have tragic consequences if left unchallenged. This note spotlights detectability issues and recommends ways of improving survey integrity and quantifying detection assurance levels.

Background

Using geophysics to locate UXO is in some ways analogous to mobile phone reception. If the signal is weak you may not be able to distinguish enough of a conversation to make it understandable or you may lose the connection altogether. So it is with searching for a buried UXO target. In some settings the so-called signal-noise ratio is high (good 'reception') and a UXO may be found close to the theoretical limits of detection of a particular instrument. In other settings such as made ground comprising material which interferes with the signal relating to the UXO, the signal-noise ratio is low and it may not be possible to differentiate UXO (bad 'reception'). Unless you are scanning over a sand box or other non-magnetic or non-conducting material that has no effect on the response of a UXO then the theoretical limit of detectability is always compromised. Figure 1 demonstrates the effect of geophysical 'noise' for a magnetometer survey to detect a ferrous UXO target.

UXO detection and clearance contractors are paid to certify that an area which has been scanned is clear of UXO before construction activities can commence. It is essential therefore to quantify a detection assurance level ie the distance from a sensor less than which UXO of a certain size can be detected with 100% confidence. This measure will vary from site to site and within a site depending on the variable composition of made ground or geology and the specific target size.

It is a straight forward matter to quantify site specific detection assurance levels. The first step is to measure the background geophysical response of a site. A 1ha site, for example, would take an hour to scan in a reconnaissance sweep using surface detection methods for shallow UXO. The data provided can then be analysed using customised software to provide information on the detectability of the target size UXO. On relatively 'clean' sites a 10kg High Explosive (HE) shell buried at 3m may be detectable from surface but the same target may only be detectable to 1.5m on more 'noisy' sites (see Figure 2). The detection assurance level at which 100% of the target size UXO can be detected is thus an essential measure which should be provided for every UXO detection survey as evidence of the claimed effectiveness of the survey.

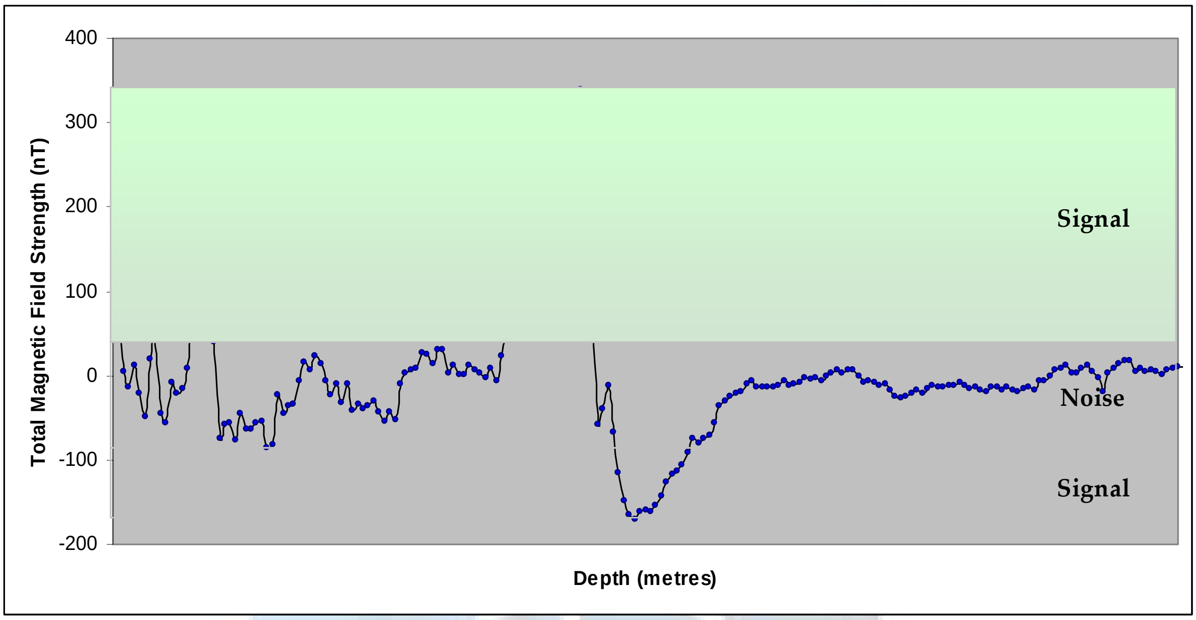

Figure 1 Magnetic signal response adjacent to ferrous UXO target in a borehole showing site noise 'envelope'

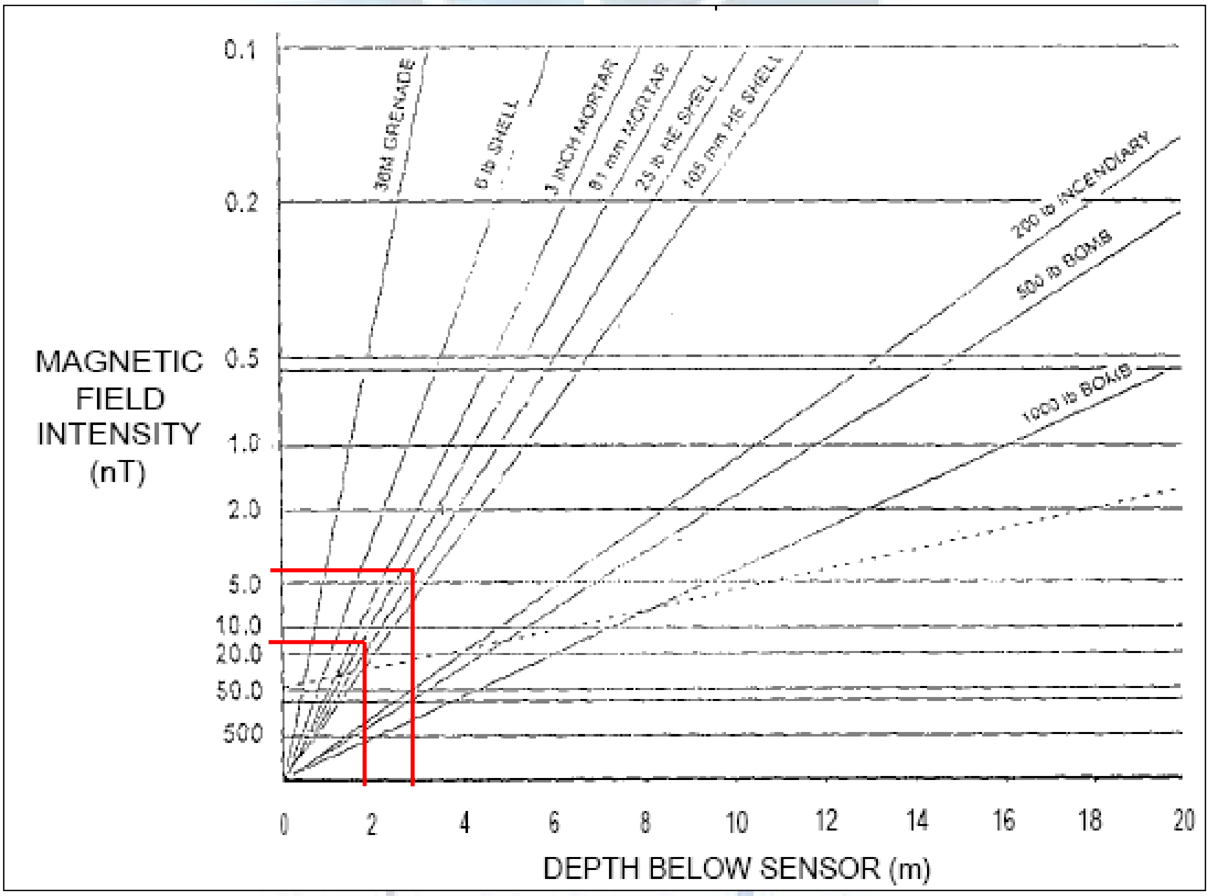

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Figure 2 Graph of detection depths versus magnetic signal strength for various ferrous UXO targets (from Stanley). Lines highlight different detection depths for 10kg HE shell where site noise 'envelope' is approximately 5nt and 15nt.

A further reason for determining the background geophysical response of a site before carrying out a survey is to help design a site specific survey which is appropriate to meet the objectives of the investigation. This principle applies to all geophysical methods including magnetometer surveys for ferrous targets and electromagnetic surveys which include non-ferrous targets. Sites with varying levels of interference may require different survey parameters such as traverse line spacing, sensor elevation and sampling interval. All too often surveys are carried out without any thought being given to these issues, potentially undermining the survey effectiveness.

Equipment limitations

In the UK, UXO detection services have traditionally been provided using analogue instrumentation. Such a survey relies on the diligence of the operator to detect audio tones or deflections in a needle. No permanent record of coverage or data quality is preserved. This may be expedient in a live military situation and in certain limited scope clearance applications but is inappropriate for larger scale UXO detection contracts.

Modern UXO detection technology in contrast provides high integrity digital data with a permanent record of data coverage and quantifiable search effectiveness (see Figure 3).

There is no doubt which is the more defensible approach in the event that an incident involving UXO were ever to occur. Largely because of a lack of awareness, analogue instruments for site clearance continue to be widely used in the UK without due consideration of the alternatives.

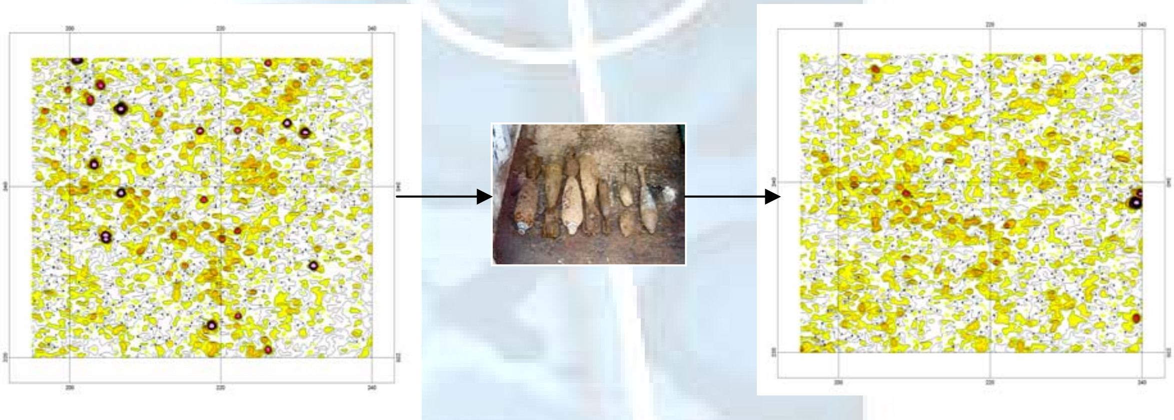

Figure 3 Example of the results of scanning an area using digital gradient magnetic survey to detect ferrous ordnance items (left). The located items (centre) were removed and the area rescanned (right) to unequivocally prove that all ordnance items had been removed.

The following anecdote provides shocking evidence of the claims being made by some contractors regarding the effectiveness of their instrumentation:

The main risk identified on a site was thought to be from unexploded aerial-delivered bombs of approximately 10kg as well as other smaller calibre unexploded ordnance related to the site's history and military activity. The client had issued a specification to detect these UXO to depths of up to 6m below ground level. A well known EOC firm recommended a solution to this problem using standard military issue detection equipment from the surface. A call to the manufacturers of the equipment, who provided official detection ranges, resulted in a table of detection being issued to the customer to provide unequivocal evidence of the limitations of the equipment actually being utilised. A similar table is reproduced below.

Table 1: Table comparing detection depths (derived from different manufacturers)

	Detectors		
	Type 1	Type 2	Type 3
UXO type	**Max detection depths (m)**		
German Bombs:			
SC-50 (50kg)	**1.5**	**1.5**	**0.8**
SC-250 (250kg)	**4-5**	**3**	**1**
SC-500 (500kg)	**5**	**3.5**	**1**
SC-1000 (1000kg)	**6**	**3.5**	**1**
UK Ordnance:			
Small arms <9mm calibre	**0.1**	**-**	**0.2**
Medium calibre <20mm	**0.2**	**0.2**	**0.3**
Mortars <2inch	**0.4**	**0.6**	**0.4**
Mortars <3inch	**0.5**	**0.8**	**0.4**
Shells <3inch	**0.5**	**0.8**	**0.4**
These detection depths represent the maximum under ideal site conditions. In most cases detection depths will be less than stated here.			

In this case the specified UXO target and burial depth (10kg device to 6m depth in soft soils) was well outside the detection range of the instruments proposed by the EOC contractor. Figure 4 illustrates the importance of selecting the correct method to provide assurance that a target can be detected.

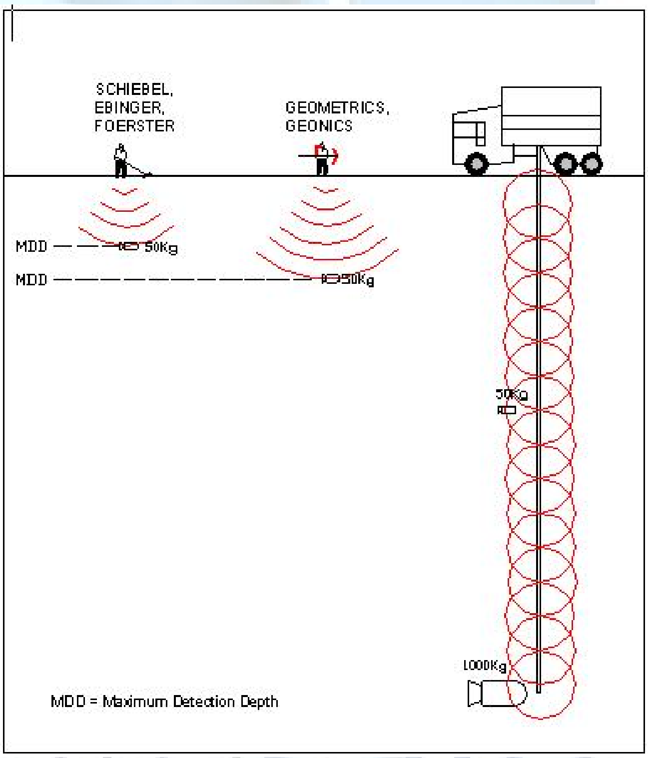

Figure 4 graphic showing relative detection depths of different systems

Effectiveness of borehole / CPT surveys

Sites in high risk areas with soft geology may be underlain by unexploded WWII aerial-delivered bombs of 50kg and larger at depths much greater than the maximum detection depths achievable from surface (see Figure 4). The ferrous nature of most such UXB makes a magnetometer the most appropriate instrument for detection in boreholes or CPT (Figure 5).

Modern magnetometers are extremely sensitive and routinely capable of detecting larger UXB (<250kg) within a 6.0m diameter zone around the probe position. A WWII 50kg German bomb is theoretically detectable within a 4m diameter. The choice of instrument and recognition of the influence of site conditions are, however, critical steps in survey design to ensure survey effectiveness.

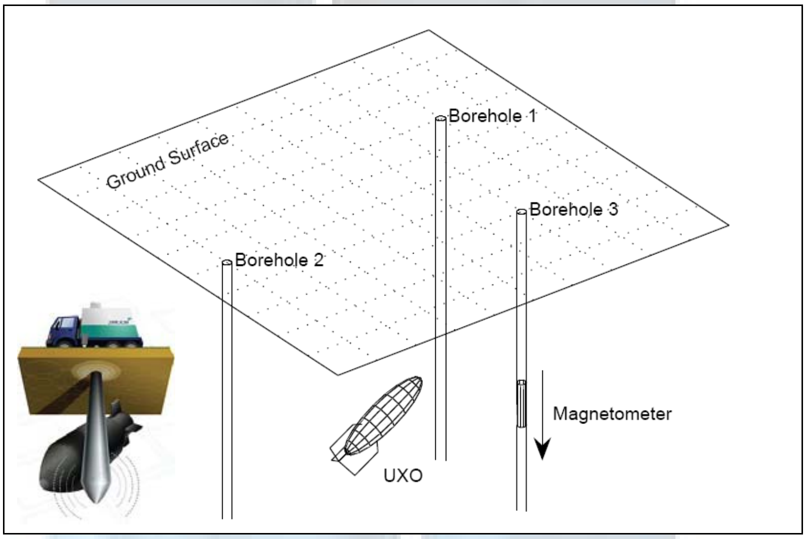

Figure 5 Schematic layout of boreholes used to probe for the location of UXB (CPT in inset)

Zetica have established a test shaft at their test site in Oxfordshire to prove the limitations of various instruments available for UXB detection and improve survey effectiveness. Figure 6 shows a schematic layout of the site with gantry in place to lower bombs to chosen depths and chosen orientations. Figure 7 presents a comparison of data acquired at the test shaft and modelled UXB data.

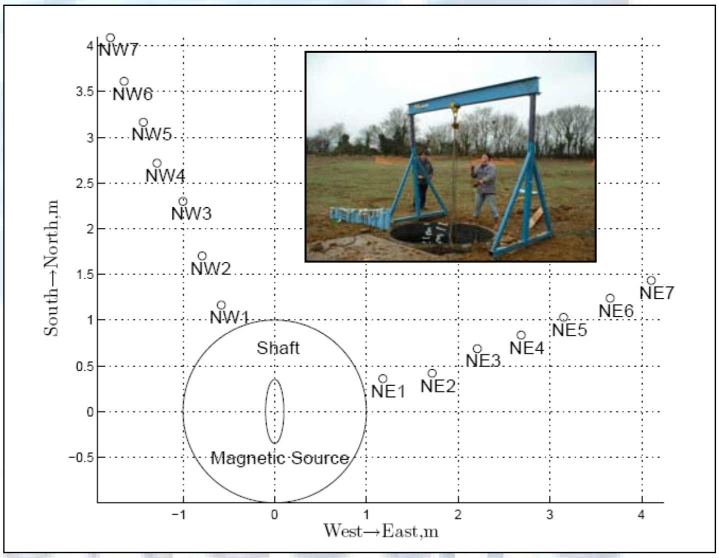

Figure 6 Layout of boreholes around test shaft (NE and NW directions only shown).

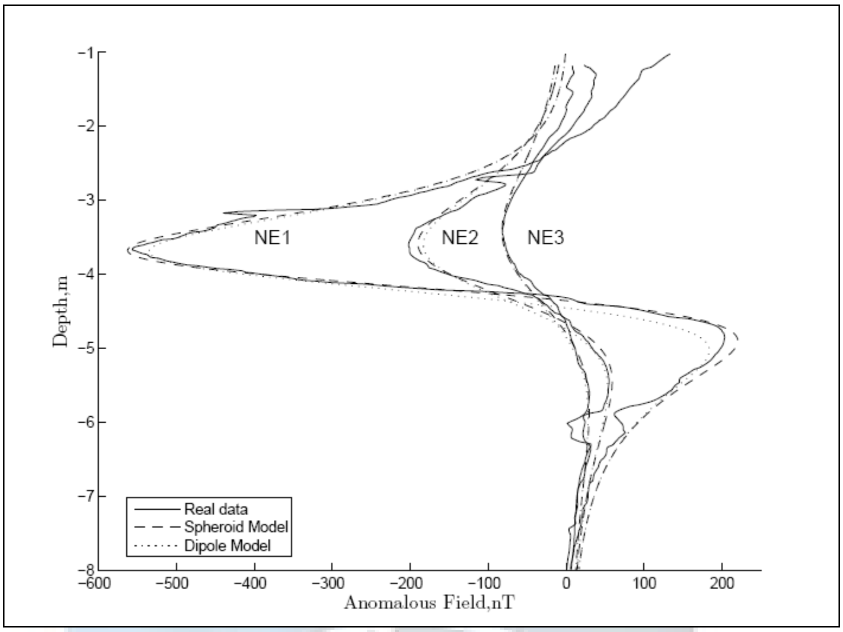

Figure 7 Example of real and modelled borehole total field magnetometer data for 3 boreholes 1m, 1.5m and 2m away from a 50kg bomb (Zetica test site)

Zetica recommend the use of total field magnetic instruments which are much more sensitive to ferrous targets than gradiometer-type magnetometers. The gradient anomaly associated with a target attenuates more rapidly with distance than the total intensity anomaly so detection distance is always less.

At distances exceeding the detection radius of the instrument the amplitude of the anomaly resulting from a UXB is equal to or less than the peak-to-peak amplitude of the background noise. It is worth emphasising again that the noise signature of a site is affected by natural geology and objects in the made ground and is consequently site specific. If this fact is ignored and the detection radius is overstated based on unrealistic site conditions, potential targets could be missed. For example, an exaggeration of the radius of detection by just 20cm, say from 1.8m to 2m, could result in overlooking 2,400m^2 for every 1000 probes measured.

To provide assurance that UXB can be detected with '100% confidence' requires that the background noise on the site be characterised. The authors have undertaken a study based on thousands of probes carried out over the past 5 years using CPTs and boreholes over many different sites in order to determine 'typical' noise levels and the corresponding influence on limits of detectability for various UXB target sizes.

Figure 8 shows measured site noise data from two different sites superimposed on the simulated anomaly from a 50kg bomb located south and west of the measurement borehole. Differences in background noise are readily apparent as is the difference in signal strength of the same bomb depending on whether the measurement borehole is north or west of the target.

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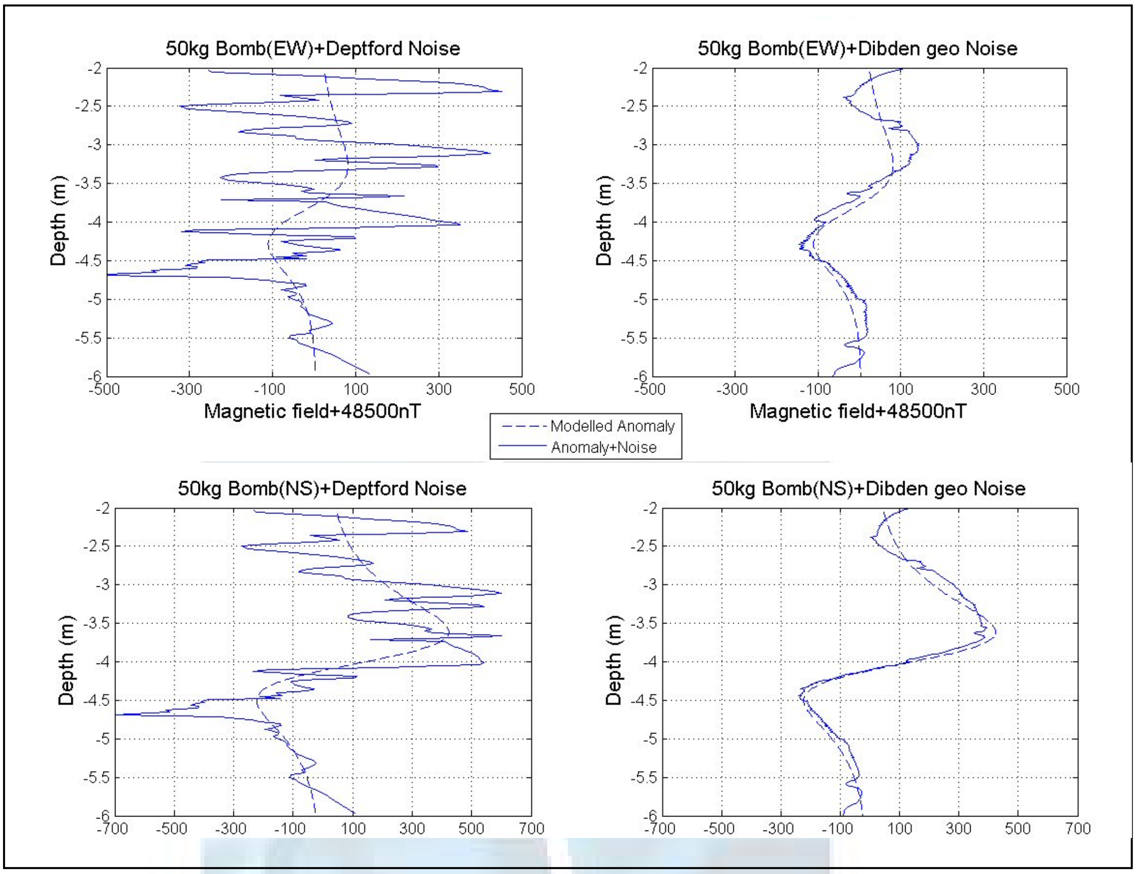

Figure 8 Examples of site noise added to modelled data for a 50kg bomb measured north (NS) and east (EW) of the target

In order to better understand the effects of noise on the limits of detectability and develop a means of quantifying the detection radius for a particular site and target combination, the modelling work was expanded to accommodate a 2d grid of points.

An 11 x 11 grid of probe positions was developed around a central target location (Figure 9) and the data for each position were simulated using proprietary software. The theoretical anomalies (verified by data from the Zetica Test Site) generated by the software for each location were superimposed with actual background magnetic 'noise' data.

This process was undertaken for a range of bomb sizes and orientations and background noise levels.

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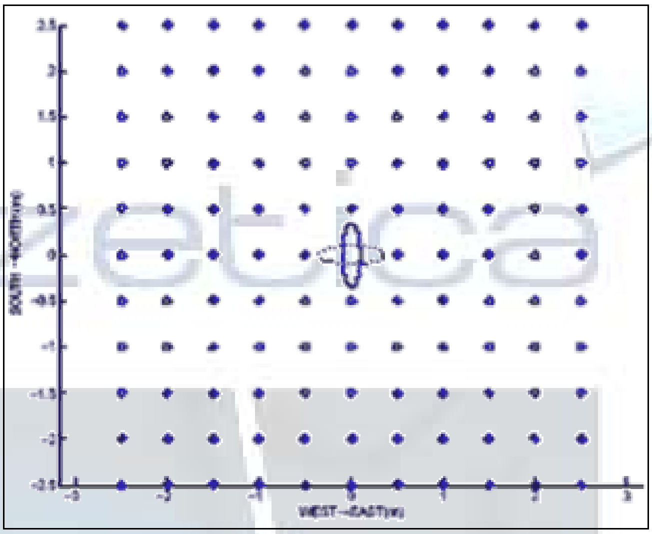

Figure 9 Layout of boreholes around bombs for modelling exercise

An inversion function was applied to estimate the distance, depth and moment parameters for the target UXB at each grid position. An example of the output of the programme is shown below for a 50kg bomb in a north-south orientation on a site with low noise.

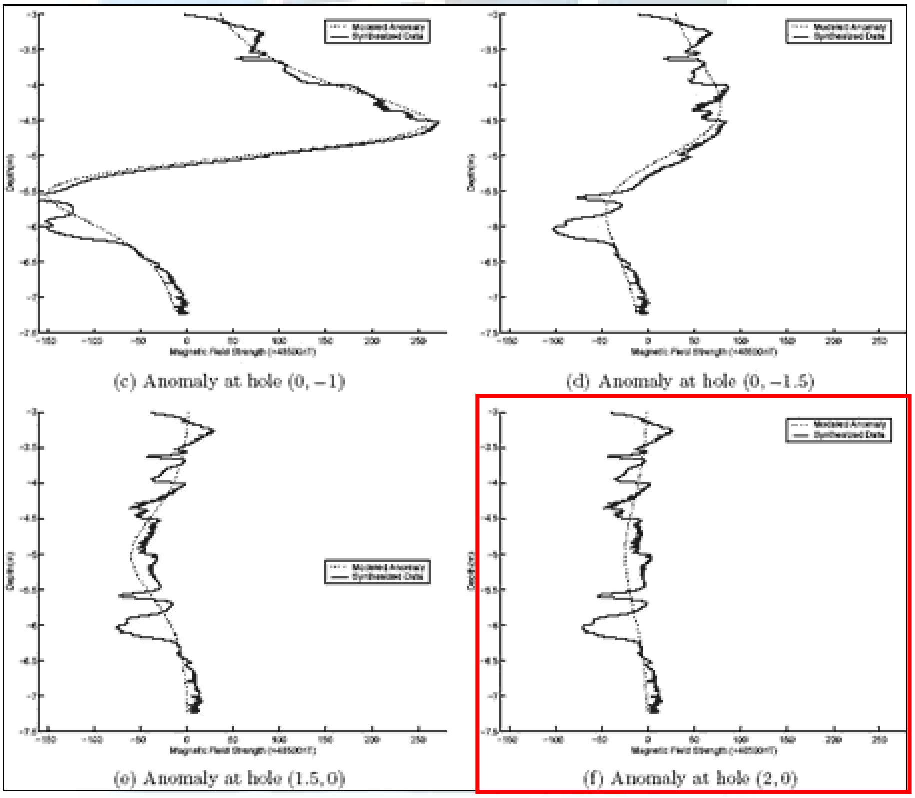

Figure 10 Modelled anomaly (dotted line) and data (solid) for a 50kg bomb at various detection distances in a low noise setting.

The key point to note in this example is that in theory a 50kg bomb can be found at 2m distance but in practice this would be impossible with the level of noise as shown in the red box in Figure 10).

The output of the modelling and inversion permutations was combined to produce so-called distance and depth bias plots.

Figure 11 illustrates distance and depth bias plots for a 50kg UXB in a low noise setting. The grids are colour shaded depending on the level of bias at each grid point, with blues indicating low bias values.

The region of the grid where the detection confidence level is high ('100% confidence') is defined as the overlapping part when both distance bias and depth bias are relatively small. This is closest to the target near the centre of the grid. Beyond this region, the level of confidence drops off with increasing distance, although initially the target may still be detectable. This is defined as the area of low confidence. Outside this region no anomaly can be detected in the data hence the confidence in being able to detect the target is low (no confidence).

The boundary of each region is defined statistically and is dependent on the size and orientation of the bomb as well as the specific background noise level on the site. The results of each model are summarised in a Detection Assurance Level table such as that in Table 2.

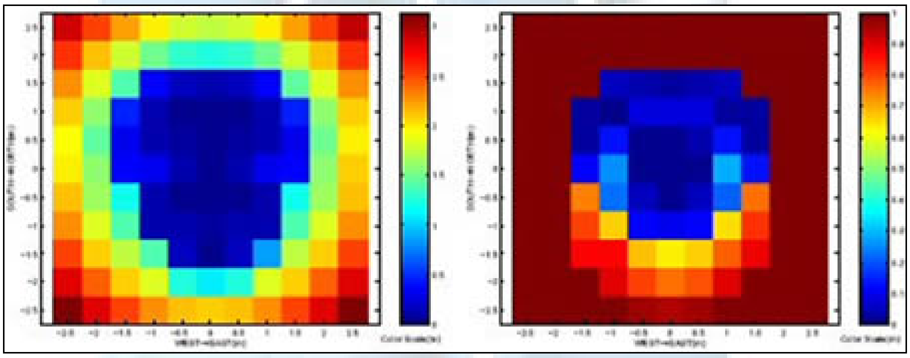

Figure 11 Depth (left) and distance (right) bias plots for a 50kg bomb in a low noise setting

Table 2 Detection assurance levels for borehole detection of the most common bomb sizes at four different sites in the UK

Bomb Type	**50kg**			
Detection assurance level (radius in m)	Deptford	Dibden	Ashburton	Lewes
'100% confidence'	<0.5	<1.5	<1	<1
Low confidence	0.5 ~ 1	1.5 +/- 0.5	1 ~ 1.5	1 ~ 1.5
No confidence	>1	>1.5	>1.5	>1.5

Bomb Type	**250kg**			
Detection assurance level (radius in m)	Deptford	Dibden	Ashburton	Lewes
'100% confidence'	<1	<2	<1.5	<1.5
Low confidence	1 ~ 1.5	2 ~ 2.5	1.5 ~ 2.5	1.5 ~ 2
No confidence	>1.5	>2.5	>2.5	>2

Bomb Type	**500kg**			
Detection assurance level (radius in m)	Deptford	Dibden	Ashburton	Lewes
'100% confidence'	<1	<2.5	<2	<1.5
Low confidence	1 ~ 2	2 ~ 3.5	2 ~ 3.5	1.5 ~ 3
No confidence	>2	>3.5	>3.5	>3

It is clear from Table 2 that a radius of detection can only be objectively estimated based on actual site conditions. 3m for a 250kg bomb on one site may only be 2m on another and vice versa. This can have a significant impact on the costs of mitigating the risk of UXB on a site. Those operators who ignore these facts are either putting operations at risk or charging you more than you need to spend.

Conclusions

A methodology for optimising survey effectiveness and providing quantifiable detection assurance levels has been proposed. It is recommended that companies requiring UXO detection surveys specify that survey design parameters should be justified in terms of target size, depth of burial and anticipated or quantified site conditions and that equipment / processing capabilities should be certified by a 3rd party.

References

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