The Risk of Unexploded Ordnance on Construction Sites in London

Authors

Marc Owen, Skanska Building UK

Andrew McNamara, MSc, PhD, City, University of London

Jignasha Panchal, MEng, PhD, City, University of London

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CDM Construction Design and Management

CIRIA Construction industry research and information association

FoI Freedom of Information

HE High explosives

HSE Health & Safety Executive

UXB Unexploded bomb

UXO Unexploded ordnance

WW2 World War 2

Abstract

Greater London, among many large cities, was subject to bombing by the German military in both the World Wars and was the target of many air raids during the Second World War (WW2). This was particularly the case during the Blitz, September 1940 – May 1941, when over 28,000 high explosive bombs and parachute mines were dropped on London. Post war research conducted in 1949 estimated that approximately 12,750t of bombs, including V1 and V2 rockets, were dropped on London. The night of 16th –17th April 1941 was one of the worst bombing raids, when 446t of bombs were dropped on London and over 58t did not detonate. Unexploded bombs remain buried underground today, as they were unidentified at the time or abandoned owing to difficulties in recovering them. Uncharted bombs continue to pose a potentially significant hazard for developments around London. This paper considers the probability of discovering unexploded ordnance (UXO), particularly WW2 ordnance, during intrusive groundworks in London. The prevalence of unexploded ordnance has been assessed using data obtained from governmental organisations to estimate the likelihood of discovery in London.

Introduction

The Construction Industry Research and Information Association (CIRIA) published guidance on the management of risks associated with unexploded ordnance (Stone *et al.*, 2009). The principal purpose of the guide, supported by the UK Health and Safety Executive (HSE), was to "*provide the UK construction industry with a set and defined process for the management of risks associated with UXO from WW1 and WW2 aerial bombardment*".

The geographical area considered within this paper has been limited to Greater London (defined in Figure 1) which suffered considerable bomb damage during WW2. This area has since undergone widespread redevelopment and historical information on the discovery of UXO is widely available from public bodies. The CIRIA guide (2009) reports that "*unexploded*

ordnance resulting from aerial bombardment continues to be encountered [in] … London in particular, especially during construction and redevelopment works."

The term 'UXO' defined by CIRIA (2009), refers to any type of unexploded ordnance, whilst 'UXB' specifically refers to unexploded bombs, which are usually delivered aerially. The risks associated UXO and UXB vary and once encountered should be dealt with accordingly.

The CIRIA guide (2009) describes the most common types of ordnance that pose a significant UXO risk. Aerial delivered high explosives (HE) were designed with relatively thick walls, therefore would usually withstand impact with the ground. Instead of detonating, the UXO could penetrate the ground and become embedded at depth. This outcome is less likely for other aerial ordnance owing to their thin wall construction. Unexploded WW2 anti-aircraft artillery shells from 'friendly forces' are commonly discovered but they are unlikely to be found at depth and contain much less explosive than HE bombs. Therefore, the detonation of concealed HE bombs pose a critical hazard to contractors working below ground level.

Background for research

Over the last 10 years it has become common practice for piling contractors to request evidence that a site is clear of UXO. In the past, clients rarely undertook a risk assessment, hence the responsibility in providing this was subsequently passed onto the main contractor. Less diligent contractors ignore the risk and merely assume that UXO will not be encountered, thus providing a more competitive tender. More recently, planning permission notices have specified a requirement to detail the UXO risk mitigation measures that will be in place.

A preliminary risk assessment conducted by a specialist company will usually recommend completing a detailed risk assessment. This second desk study usually identifies a low/medium risk of UXO and will almost always recommends an intrusive survey across part of the site to locate potential UXO. These surveys do not commonly reveal any UXO. Lang *et al* (2015) challenged the reputation of the UXO industry and noted that "*developers are seeking a second opinion on… UXO risk assessments due to the apparent disparity between*

the evidence presented in the reports and the often extensive risk mitigation recommended… by some UXO specialists, which on the surface seem only to be dedicated to increasing their sales".

Risk assessment process

The Health and Safety at Work Act, 1974, requires steps to be taken to reduce risks so far as is reasonably practicable, which means "*balancing the level of risk against the measures needed to control the real risk…* [and]*…it is not necessary to take action if it would be grossly disproportionate to the level of risk.*"

A large HE bomb exploding has the potential to kill numerous people, however the likelihood of this event maybe very low.

Whilst attempting to develop a realistic UXO assessment process for the Crossrail works, it was quickly realised that the simplistic concept of 'risk = probability multiplied by consequence' would not work in a "*practical and meaningful way*", owing to the high potential for a UXO to cause harm (Smith *et al*., 2014).

CIRIA (2009) suggested a four stage assessment approach:

- Stage 1. A preliminary risk assessment, which can be performed by a non-UXO specialist, suggesting that most sites are anticipated "*as having a low probability of a UXO hazard*".
- Stage 2. Detailed risk assessment estimating the "*likelihood of creating a UXO hazard*", completed by UXO specialists.
- Stage 3. Risk mitigation to 'eliminate risk or reduce to an acceptable level', which should ensure that "*an efficient and cost-effective risk mitigation programme is selected*".
- Stage 4. Implement risk mitigation plan.

The probability of encountering UXO

The CIRIA guide (2009) states that "*there is no available data regarding the number of UXO incidents on construction sites within the UK*" and "*it is estimated that about 15,000 items of ordnance ranging from high explosive … bombs to smaller items such as mortar rounds and grenades … have been removed from UK construction sites*" between 2006 to 2008 but "*estimated that about five per cent were live*". This information was provided by two of the UK's largest, but unnamed, UXO specialist companies and the figure would be higher if data was collected from a wider pool. This implies that more than 250 substantial items of live ordnance are discovered annually on construction sites. Anecdotal evidence from UXO contractors suggests that the probability of discovering UXO on construction sites remains high.

Local Authorities kept records of the location and type of bombs that were dropped during WW2 as part of the government's Air Raid Precaution requirements. Some were detailed and accurate, although errors occurred when numerous bombs were dropped and safety was the primary concern over record keeping.

Post raid surveys were carried out by the emergency services staff to identify UXO as reported in the CIRIA guide (2009). Confirmed or suspected UXBs were reported in the Bomb Census and the rate of HE bombs that failed to detonate is accepted by the industry to be approximately 10%, which reflects estimate of the Home Office's Chief Scientific Adviser (Hunt, 1949).

Unfortunately, this failure rate is sometimes misinterpreted and it is suggested all UXB still exist. In 2007, the BBC quoted a risk assessment that suggested "*of 1,493 high explosive bombs* [that were dropped on the Olympics site during WW2], *207 remain unexploded*".

Following WW2, the British estimate of the tonnage of German bombs dropped was compared with German military sources. The 16th-17th April 1941 raid described by Hunt (1949) estimated 446t of HE bombs were dropped. However, German sources suggested 890t HE bombs and a further 151t of incendiary bombs were dropped. If the British consistently

underestimated the tonnage of bombs dropped, but accurately counted the UXB, then the actual failure rate would have been overestimated.

These figures have little relevance today as the danger posed by UXO was generally well understood during the war and known UXO were identified and cleared by bomb disposal units. It is worth noting that ordnance, if present, is likely to be found in made ground, river terrace gravels or the upper levels of London Clay.

A number of UXBs were abandoned during the war owing to limited resources required to clear them, higher priorities elsewhere or their location. Following the war however, significant efforts were made to investigate and remove them. By June 1946, 99 bombs that had been approved for abandonment in London; of these 62 were "virtually discredited", "not proven" or "yielded no trace", i.e. probably never existed. There was "tangible evidence" for the remaining 37, however these were "*all in positions which, having regard to their estimated size and depth, constitute no danger to the public*". Twelve bombs weighed 50kg or less and were located in cemeteries. "*The rest are mostly estimated at 50kg and deep in water-logged soil in marshes, banks of rivers, or reservoirs, sewage farms, refuse pits…*" (McIvor, 1946). A report to Parliament stated that 89 abandoned bombs remained in London at 74 sites (Hansard, 1996).

The UXBs that escaped notice at the time of landing are now the primary hazard. As they were not identified it is essential that risk assessments are undertaken to assess the likelihood of it encountering them.

Copping (2008) reported 21,000 potential locations in Great Britain of UXBs. As bombs were dropped in sequence it was claimed that their location could be determined by identifying demolished buildings and give a very good indication of whether "*there is a bomb in the vicinity*". Jones *et al.* (2013) estimated that during the Blitz 28,000 bombs were dropped on London, therefore the 21,000 UXBs remaining in Great Britain appears surprisingly high. This statistic may have ignored the UXBs that were identified and removed during and immediately after WW2.

Review of sample risk assessments

A sample risk assessment presented in the CIRIA guide (2009) makes an assumption on this probability of encountering UXBs and is indicative of the difficulty experienced in making an objective assessment. Figure 2 is a reproduction of a map showing the locations of bombs identified during WW2. The sample risk assessment states that *"there are records of several bombs falling on the site itself. There is credible evidence indicating a high risk of potential UXB being present on the site*", however the relationship between past bombing and the presence of UXB is not explained nor is 'high risk' defined.

The sample report suggested that the density of UXBs remaining in Rotherhithe, London was either one, two or three 50kg bombs per hectare. There is however no justification for these values, except to advise that it is prudent to assume that there is at least one UXB/Ha. The density of remaining UXBs greater than 50kg is not postulated. London County Council (LCC) bomb damage maps (Saunders, 2005), referenced in this particular risk assessment, suggests that between 200 and 300 bombs were dropped for every 1000 acres in Greenwich, London which equates to 0.49 – 0.74 bombs per hectare. On the basis that approximately 90% of these bombs exploded, the assumption that 1 UXB/Ha remains appears to be implausibly high without additional justification.

The assessment of a Paddington site states that 151 HE bombs were dropped over 100Ha. The typical maximum failure rate for UXO was assumed as 15% and the factors influencing the probability of discovery were listed. This assessment made a subjective estimate that it was 30% likely that UXO were not detected during WW2. This resulted in a residual UXB density of 0.07 UXB/Ha, which equates to a probability of 14%, given the size of the site. The probability of encountering UXO is then reduced to 0.94%, as excavation is limited. This is defined as a 'moderate probability' and that "*if UXO is found, the likelihood of initiating the device and causing an explosion is substantially lower*". The report suggests that in such instances, an Explosives Safety Supervisor is not justified and that an ordnance briefing is

sufficient for site personnel. Therefore, a moderate probability can be considered as an acceptable and manageable risk.

The LCC bomb damage maps state a bombing density of between 200 and 300 bombs per 1000 acres for this area, which equates to 0.49 – 0.74 bombs/Ha. Adopting the upper figure, combining it with a 10% failure rate (CIRIA, 2009) and an assumed non-detection rate of 10% reduces the residual UXB density to 0.0074 UXB/Ha. This is equivalent to one UXB per 135Ha; an order of magnitude lower than the second risk assessment.

The potential residual UXO density ranges from three 50kg HE bombs per hectare, to one UXB per 135Ha, demonstrating the degree of subjectivity that exists when completing risk assessments.

Literature sources

The observations presented in this paper provide additional data in an attempt to quantify the probability of encountering UXO and UXBs on construction sites in London over a twelve-year period. The five sources of information are as follows:

- Freedom of information (FoI) requests made to the Ministry of Defence (MoD)
- FoI requests made to the Metropolitan Police Service (MPS)
- FoI requests made to the London Fire Brigade (LFB)
- FoI requests made to various London Boroughs
- FoI requests made to the Health and Safety Executive (HSE)

The MPS are responsible for coordinating suspected UXO incidents, have explosive ordnance disposal teams and can be expected to have information regarding the location of every UXO discovery. The LFB would attend if there was a risk of fire in the event of detonation. Local authorities may record the incident if it was brought to their attention or to provide temporary shelter for displaced residents.

Ministry of Defence

The MoD estimated a total of 424 WW2 air dropped weapons were made safe between 2010 and 2016 across the UK by the Army; 34 of these were German HE bombs, whilst 316 were 1 or 2 kg German incendiaries. Within London, there were seven German HE or large incendiary devices discoveries between 2004 – 2016, averaging 0.54 UXBs per year.

Metropolitan Police Service records

The Metropolitan Police deal with explosive ordnance incidents within the Greater London area. From 2004 – 2007 and 2009 – 2014 the MPS attended 1533 incidents involving 'live ordnance', requiring assistance from their explosive ordnance disposal teams. The scale of these incidents could range from a firework to a terrorist attack and the types of ordnance were not specified, so may not have originated from the war. 560 of these incidents were analysed to identify if they were on construction sites. An initial review showed that 5 of the 560 incidents were thought to have occurred on construction sites, however further analysis revealed that one incident did not involve ordnance. If these results are representative, then simple extrapolation suggests that about 12 UXO discoveries on construction sites were sampled over the 10-year period.

In 2015 there were three well publicised UXB discoveries in London. The MPS analysed all 105 live ordnance incidents that they attended in 2015 and revealing that three occurred on construction sites. This provides reassurance about the general quality of their analysis. If the results of all these years are combined, this would suggest an average of 1.4 incidents each year over the 11-year assessment period.

London Fire Brigade records

The LFB press release (2015) stated that since 2009 they had attended to nine WW2 UXBs. A freedom of information request revealed further details about the UXBs and were cross-referenced to contemporaneous reports from the Internet. Of the nine events, there was independent corroboration of UXO for two incidents. References could not be found for four

of the incidents and three were reported by the media as non-ordnance items, such as a light fitting or a piece of metal.

Omitting the three incorrectly reported occurrences leaves a revised figure of six possible UXB incidents. The LFB described one uncorroborated incident as involving an incendiary device as opposed to a HE. At another incident the Police removed an item 30 minutes after arriving on site, which suggests that it was not an air dropped HE UXB.

Corroborating evidence could reasonably be expected given the involvement of other authorities and the significant media interest in these events. For the same period, the Army only dealt with 2 UXBs, so it would be unlikely that the LFB dealt with 6 UXBs. As such, it has been assumed that the 4 unconfirmed events were UXO and not UXBs. Therefore, across 80 months the rate of discovery was on average 0.15 UXBs each year, but this figure is not limited to construction sites.

London Boroughs

Freedom of Information requests were made to the London boroughs and the City of London for the number of WW2 UXBs located in their borough between 2004 – 2015. The quality and level of detail of the data varied, however 17 responses were received representing over half of the 33 London boroughs. On average there were 3.1 incidents each year, which included all types of WW2 ordnance, such as: British anti-aircraft artillery shells, grenades, war-time trophies and UXO dredged from the sea for aggregate. Assuming this figure was representative of all the London boroughs, the average number of UXO discoveries equates to 6 items of UXO/year across London, but not limited to construction sites.

Summary of incidents

Table 1 summarises all the known incidents. It should be noted that the location of a small number of UXO incidents is unknown and in these cases it was assumed that they were not on construction sites.

Ten UXBs were discovered in the 12-year period, averaging 0.83/year. On construction sites in London this average increases to 1.7 incidents/year involving any type of live ordnance each year.

It is reasonable to assume that the period during and immediately following WW2 posed the highest UXO risk when undertaking clearance or construction work in London. The discovery and progressive removal of UXO has steadily been conducted since. In addition, much of London was rebuilt following the war and some has since been redeveloped. Considering these factors, the probability of discovering UXO is gradually diminishing. However, the annual rate of discovery rate may also be influenced by the economic state of the country; a rise in construction projects may lead to more ordnance encounters.

Comparison of UXO discovery rate, by source

For the time period 2004 – 2015:

- data from the Army suggests 0.5 UXB/year at any location (omitting 2016 figures);
- LFB reports suggest an average of 0.15 UXB/year at any location;
- figures from the London Boroughs suggest an average of 6 UXO incidents/year at any location;
- MPS figures suggest an average of 1.4 incidents/year on construction sites, involving any sort of 'live ordnance';
- The consolidated analysis suggests an average of 1.7 UXO incidents a year on construction sites and an average of 0.83 UXB/year, at any location.

These figures broadly correlate and there is a notable difference between the estimate in the CIRIA guide (2009) who suggest that significantly more than 250 live UXO items are discovered annually on construction sites in the UK. It is likely that ordnance in London was cleared by UXO companies, however CIRIA (2009) state that "*where high risk UXO is discovered (eg German WW2 aerial delivered iron bombs) the appropriate military bomb disposal unit will be required to deal with it*". In addition, the UXO discovery evacuation plan

suggested in the CIRIA guide (2002) specifies contacting the police if suspected ordnance is discovered. It is possible that this discrepancy occurs because significant quantities of ordnance are found in single incidents or clustered in small high risk areas, such as former military sites or factories outside London, during redevelopment.

Likelihood of discovery

Under the Construction (Design and Management) Regulations (2015), there is a legal obligation to submit a F10 form to the HSE if the duration of a project or the number of people working on it is expected to exceed a set threshold. CDM Regulations were first introduced in 1994 and this requirement has existed since that time thus providing a good indication of the number of construction sites that were established. Whilst it is accepted that some of these projects do not penetrate the ground, other non-notifiable projects (such as many domestic extensions) may involve ground works. The HSE provided details on the number of F10 forms that were submitted over the 12-year period in question to quantify the probability of discovering ordnance on a construction site. There was at least one instance (albeit not in London) where an aerial delivered UXO was discovered in the wall of a building; there is the potential for this to occur elsewhere.

Between 2004 and 2015 almost 141,000 F10 forms were submitted for London based sites. On the basis that an average of 1.7 'live' UXO incidents were reported on construction sites each year, there could have been as many as 21 incidents over the 12-year period requiring assistance from statutory authorities. This would suggest that UXO of any type are discovered on average every 6,700 sites. It is not possible to accurately assess the number of UXBs that were found on construction sites with the information available. If it was assumed that all 10 UXBs were found on construction sites, this would suggest that one UXB is discovered for every 14,000 sites which require F10 notification. However, eight UXB discoveries is probably correct; the two omissions were found at a quarry and during road resurfacing, which would result in one UXB discovery for every 17, 600 sites.

Risk of detonation

The CIRIA guide (2009) acknowledged "*in real terms, the likelihood of detonating UXO are far lower than that of encountering one*"; a sample risk assessment describes it as a "*remote chance*", that "*decay usually results in a device becoming less susceptible to initiation*" and "*if UXO is found, the likelihood of initiating the device and causing an explosion is substantially lower*" than encountering it.

Mitigation measures

Detailed risk assessments usually include a recommendation to complete a penetrative ground survey and the employment of a UXO banksman to monitor excavation works. The value of the surveys can be questionable when there is existing "contamination" present, perhaps in the form of redundant piled foundations. CIRIA (2009) acknowledges that the clearance certificates provided to clients following UXO site surveys do "*not constitute a guarantee that the site is clear of UXO*" and that "*no current UXO detection survey technology can provide complete assurance that every buried UXO item has been detected… Even the most reasonably practicable method… will leave some level of residual risk*".

Smith *et al.* (2014) articulated the experiences of UXO mitigation during Crossrail site investigation works. Significant efforts were made to reduce the number of sites that required surveying. At the time of publication, 81 locations had been subject to risk mitigation measures and "*no confirmed UXO were recovered or detected at any location. In two boreholes, ferrous objects were detected at depth, and recorded as possible UXO, resulting in the ground investigation location being relocated circa 10m away. In one of these positions, it was suspected that the object detected was a redundant retaining wall tie, but records were not available to confirm this. The nature of the object in the second case remains unknown*".

The question is raised as to whether the proposed mitigation measures are proportionate; given the apparent low discovery rate; the low chance of a UXB detonating and the high cost of mitigation works that are sometimes recommended.

The risks posed by the mitigation measures themselves must also be acknowledged. During the early investigative works for Crossrail, it was noted that due to the number of penetrative UXO surveys that were undertaken "*the risk of a utility strike was much increased, and that therefore the overall risk faced by the ground investigation works in some cases was considered to have actually increased by those UXO mitigation measures*" (Smith et al, 2014). Placing a UXO banksman near enough an excavation to view the works, exposes an additional person to the risks posed by the detonation of a UXB.

Relative risk

The CIRIA guide (2009) acknowledged there were no known fatal UXO related incidents on construction sites in the UK since the 1940s. The media sometimes confuse the situation in Britain and the Continent. For instance, the Construction Manager magazine published an online article erroneously stating that "*over the years, a number of construction workers have been killed or injured when excavation equipment has hit unexploded bombs, particularly in the UK and Germany*"; the statement was later corrected. (Kenny, 2017).

Loss of life owing to the inadvertent detonation of ordnance in continental Europe has occurred and the European situation frequently features in UXO risk assessments. In January 2016, the Smithsonian Magazine (Higginbotham, 2016) reported that 2000t of unexploded munitions are discovered on German soil every month and "*eleven bomb technicians have been killed in Germany since 2000*". Webster (1996) states that since the French *Département du Déminage* was established in 1946, more than 630 de-miners have been killed.

The CIRIA guide (2009) note that the scale of German bombing was 20 times lower than the Allied bombing of Europe. The Germans also preferred the use of electrical fuses with a limited battery life, rather than the Allied preference for mechanical fuses, which pose a greater long term hazard. A large proportion of Allied bombing took place whilst the Germans were retreating and their forces were disorganised; making accurate reporting and disposal of UXO less likely. The WW1 land battles which used huge quantities of ordnance were never

replicated in Britain and therefore do not pose a significant threat. The disparity between the discovery rate and casualties makes comparisons between countries difficult, misleading and less meaningful.

The low probability of a fatality due to UXO on construction sites was compared with other events that would generally be regarded as low probability, in an effort to draw parallels. From April 2000 to March 2015 the HSE (2015) reported 56 fatalities at work that involved cattle; *Inquest* (2016) state between 1990 and 2015, 24 people died as a result of gunshot by the MPS; the Tornado and Storm Research Organisation estimate that an average of 2 people die every year in the UK due to lightning strikes (Elsom and Webb, 2014) and an MoD statement (2016) reported 134 members of the UK armed forced died in training in the period of January 2000 to October 2015 as the training "*necessarily involves individuals… taking some risks*", but they were "*as low as reasonably practical*" (BBC, 2016). These apparently low probability events still account for between one and eight people dying every year.

The probability of fatalities following these events could reasonably be perceived as being very low, however each of the above examples has resulted in an annual death rate that far exceeds the total number of UK construction workers killed by the accidental detonation of WW2 UXO in the last 75 years.

Conclusion

It is indisputable that the detonation of a HE WW2 bomb on a building site could seriously injure or kill numerous people and there is significant evidence that London was heavily bombed during WW2. However, it is not justifiable to link these facts and suggest that UXO automatically pose significant risks on construction sites in London. Risk assessments must be completed, however they should be based on a realistic and genuine assessment of the probability of UXO discovery, rather than arbitrary or false assumptions of its presence and over-inflating the number of UXO that remains undiscovered.

The industry should also correct the media when overstating the actual risk that UXO is present. One must question why intrusive mitigation is often recommended and whether the proposed measures are proportionate to the risk. Furthermore, consideration and quantification of what constitutes an acceptable risk from UXO to construction workers should be made given that it is accepted that the risk cannot be eliminated.

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