Hong Kong's marine UXO. The prevalence, burial depth, associated hazard and identification of marine UXO

C.Y. Shum *Fugro/Hong Kong, x.shum@fugro.com*

P.S. Lee[1], C.H. Fan[2] , A.J. Mazur[3]
Fugro/Hong Kong, ps.lee@fugro.com[1], felix.fan@fugro.com[2], a.mazur@fugro.com[3]

J. Schultze
Fugro/Berlin/Germany, j.schultze@fugro.com

ABSTRACT: Unexploded Ordnance (UXO) are military munitions that have been primed, fused or otherwise prepared for use and have been fired, thrown, dropped or propelled but have not detonated either by design or malfunction. Hong Kong saw considerable military action during WWII, with as many as one-third of the munitions used failing to detonate as intended. These UXO remain hidden but probably embedded under, or near much of Hong Kong's current and proposed infrastructure. Victoria Harbour and her surrounding waters received the majority of this UXO - from a variety of sources from 1939 through to the 1980's. Seabed currents and human activity uncover and transport these UXO, and the source sand for modern day reclamations is extracted from these same areas.

This paper reviews the proliferation and mobility of WWII era UXO in Hong Kong waters, the associated risk and modern geophysical methods used for accurate detection.

Keywords: Hong Kong; Unexploded Ordnance; Marine survey; World War 2 munitions

1. Unexploded Ordnance. Definition and sources in Hong Kong

Unexploded Ordnance (UXO) are military munitions that have been primed, fused or otherwise prepared for use and have been fired, thrown, dropped or propelled but have not detonated either by design or malfunction. For this discussion, we include other explosive remnants of war in this definition, such as unused munitions that have been dumped after an armed conflict and are no longer under any control.

Starting in 1939 with the laying of more than 1,000 naval mines by the Royal Navy, British, Hong Kong, Imperial Japanese and Allied forces all deployed military ordnance in Hong Kong during WW2 (1939 – 1945). This activity concluded post-war with the dumping of unused military ordnance and UXO in Victoria Harbour and surrounding waters through the 1980's. The years in between were marked by periods of intense fighting, enemy occupation and a heavy bombing campaign by Allied forces intended to dislodge the enemy.

Hong Kong was probably on the receiving end of more than 4,000 tonnes of military munitions (shells, bombs and mines) during WW2, compared with a reported 70,000 tonnes of enemy munitions fired or dropped on Great Britain over the same period [1]. Hong Kong has therefore received 6% of Britain's quota, but accounts for less than 1% of her land area.

Other sources of UXO not often considered are munitions jettisoned by aircrew in an emergency on the way to or from a target. These may or may not have been armed upon release, and dumped ordinance at the end of the conflict.

Figure 1. One of two WW2 x 1,000 lb AN-M65 bombs discovered on a waterfront construction site. January 2018, Convention Avenue, Wanchai (courtesy South China Morning Post)

There have been seven post-war fatalities [2] one serious injury and the total loss of one dredger trailer [3] as a consequence of uncontrolled detonation of marine UXO in Hong Kong. It is the larger UXO in Victoria Harbour and her surrounding waters that is reviewed here. These larger munitions used during the conflict are summarized in Table 1.

Table 1. Larger military ordnance deployed during conflict, Hong Kong 1939 – 1945

Item	Belligerent / Nomenclature	Weight (lb/kg)	Dimensions (m)	Estimated total quantity deployed*	Estimated quantity undetonated	Quantity recovered post-war
Contact Mine, Naval	GB / MKXIV	500 / 227	~ 0.79 D	400	39	-
Controlled Mine, Naval	GB / LMK1	650 / 295	0.96 D	700		
Aerial bomb	IJ / Type 94 GPHE	110/50	1.01 L x 0.18 D	1520	425 - 510	1
Aerial bomb	IJ / Type 94 GPHE	220/100	1.32 L x 0.24 D	930	230 - 280	-
Aerial bomb	US / AN-M30	100/45	1.02 L x 0.20 D	550	137 - 165	-
Aerial bomb	US / AN-M57	250/114	1.15 L x 0.27 D	158	39 - 47	-
Aerial bomb	US / AN-M64	500 / 227	1.44 L x 0.36 D	2139	535 - 640	3
Aerial bomb	US / AN-M65	1000 / 454	1.70 L x 0.48 D	1316	330 - 365	2
Aerial bomb	US / AN-M66	2000 / 910	1.78 L x 0.60 D	12	3	2
Air dropped Torpedoe	US / Mk-13	1700 / 770	4.18 L x 0.57 D	10	10	-
Air fired Rocket	US / FFAR 5-inch	80 / 36	1.65 L x 0.13 D	1273	320 - 380	-
Parachute (?) Mines	US / Mark 13, Mark 13-5	1060 / 482	1.73 L x 0.50D	57	18	-

*Shells from 40mm anti-aircraft cannon AA to 9.2” fixed cannon not included. **Sourced from original mission reports, [4-6]

2. Ordnance in Victoria Harbour

2.1. Coastal military objectives during conflict

Military objectives were fixed coastal or near-coastal positions in the greater Kowloon area, Stonecutters Island and the north shore of Hong Kong Islands (the dockyards, the Kai Tak airport, the North Point power station and other infrastructure). Although these objectives are well-documented, bombing of this era was not accurate, and munitions often fell short or long of their targets or were dropped in haste or otherwise jettisoned during fighting.

2.2. Marine military objectives during conflict

The attack on the Japanese convoy moored in the harbor on 16 January 1945 dwarfed any other raid on shipping at Hong Kong during the war. Many of the wartime UXO in the harbour are therefore likely have been dropped during this all-day attack [5], and it is this bombing that probably resulted in the discovery of two unexploded 1,000 lb bombs at a Wanchai north construction site in January 2018 (Fig. 1).

However, 16 January 1945 was but one of many Allied missions that targeted marine military objectives as the Imperial Japanese Navy light cruisers, destroyers, gunboats, armed cargo ships and tankers had imposed a virtual blockade around Hong Kong since 1942 [7].

There are several other examples of large air-dropped UXO discovered in recent years, but the vast majority of unexploded ordnance remain undiscovered in close proximity to (or underlying) much of the current and proposed construction activities.

The seabed is consequently littered with UXO including mines, torpedoes, shells, rockets and bombs (Fig. 2.) – either fired during action or dumped, often indiscriminately, after the conflict. Although the latter are described as “made safe” before dumping into the sea, this terminology has been applied arbitrarily.

Figure 2. Naval contact mine, Cheung Chau 1940-41. (Courtesy Gwulo: Old Hong Kong)

2.3. Accuracy and failure to detonate

On 24 August 1943, 42 x 500lb bombs all missed their Kowloon targets and were dropped into the sea, and it is estimated that 35 - 40% of the air-dropped bombs missed their target [8]. For three weeks of December 1941, Imperial Japanese aircraft dropped as many as 2,500 Type 94, 50 to 100 kg bombs on Hong Kong. Bombing accuracy was "terrible" [9] with eyewitness reports of bombs dropped from 2,000m altitude and landing on Kai Tak runway undetonated. Many of the subsequent Allied forces air raids were carried out by B-24 and B-25 bombers and aerial photographs taking during these combat missions confirm the haphazard nature of the bombing.

The population of WW2 munitions that failed to detonate as intended is commonly accepted at around 25-30% There are many well documented mechanical, environmental and human reasons for this, with for example "about one in three of the Japanese shells" failing to detonate during the Battle for Hong Kong [10].

2.4. Marine dumping and munitions migration

The official munitions dump site prior to May 1950 is off southwest Tsing Yi as shown in Fig. 4. The Marine Fill Committee [11] currently gazette the same pre-1950 ordnance dumping sites as areas for future sand dredging for reclamation purposes.

Ordnance have also been dredged in unexpectedly large quantities at Tathong Channel, southwest Stone Cutters Island and south of Junk Bay. From 2000 to 2002 more than 500 UXO items (mainly shells, mines, bullets) were dredged from East Lamma Channel – an area assumed to be clear of munitions, and dredged sand continues to be a potential host for UXO contamination [12]. This is most likely due to a common practice known as "short-dumping" – where munitions are sea-dumped on the approaches to and exit from official dumping grounds [13].

However the effect of munitions migration is likely to further spread the theoretical and initial extent of UXO contamination. The original bomb-drop or mine-laying locations noted in historical records may differ substantially from current UXO locations. These differences can be explained by at least two main reasons. The first is the inadvertent relocation of UXO through fishery activities. UXO can be dragged during trawl fishing activities, or by fishing nets pulling over the seabed surface, hooking UXO and then bringing the explosives up onboard fishing vessels. These finds are not always recorded and reported to responsible clearing authorities, but simply thrown back into the sea. The second reason for location deviation is dynamic seabed movement since the time of placement, which can result in substantial migration of the UXO.

Marine UXO may therefore be widespread and buried for years in the sea floor and then reappear - sometimes repeatedly, due to geological processes and human activity.

3. Hazard associated with World War 2 UXO

3.1. Hypersensitivity of old explosives

Most military explosives are sensitive to compression and heat as well as shock and UXO can escalate to an extremely dangerous state many years after they have failed to function as designed.

Some recent records of inadvertent UXO detonation on construction projects confirm the enduring hazard presented by these 75-year-old explosives (Table 2).

Table 2. Selected construction site fatalities, WW2 UXO

Year	Location	Comment
26 April 1978	Münsterland Germany	Excavator fitted with drilling tool encountered UXO Immediately exploded. Three fatalities.
24 February 1993	Yaumatei, Hong Kong	WW2 incendiary bomb. Partial detonation during excavation. 700 persons evacuated.
25 February 1993	Hong Kong	HAM308 dredger barge total loss. One injury. 250 / 500 lb WW2 bomb
23 October 2006	Aschaffenburg, Germany	Motorway construction. WW2 aircraft bomb detonation. One fatality, one injured.
3 January 2014	Euskirchen, Germany	Excavator struck 1,000 lb WW2 bomb. One fatality and eight wounded (two critical).
11 October 2017	Kuala Lumpur, Malaysia	MRT construction site explosion. One fatality, two critically injured (loss of limbs).
4 March 2020	South Cotabato, Philippines	Construction site, bomb exploded during mishandling. One fatality.

Explosive fills such as Trinitrotoluene (TNT) may originally have been more stable than others however the addition of grit or abrasive material enhances the sensitivity of TNT. Picric Acid is another highly sensitive explosive fill common to WW2 Japanese munitions. It is not only quite sensitive to shock and heat, but also being an acid it can react in the presence of moisture with the steel components of the bomb. It can then form hydrous ferric picrates and upon crystallisation into anhydrus ferric pirates, highly sensitive to friction and shock.

Detonators are much more sensitive to heat, friction and shock, so a bomb case without a fuze but containing an explosive fill and a detonator could reasonably be expected to react adversely, if the detonator were to be subjected to shock or compression. In both cases this would cause molecular friction to occur within the detonators' explosive compound and the result should not be unexpected.

In most bombs there is a third component in the explosive chain - a booster charge. The booster charges are made of less sensitive explosive than the content of a detonator, but more sensitive than the main explosive fill. Early bombs often used Picric Acid booster charges but this was eventually superseded by the use of Tetryl because Picric Acid is not only quite sensitive to shock and heat, but also being an acid it can react, in the presence of moisture, with the steel components of the bomb.

3.2. Unintended detonation of UXO

Unintended detonation of UXO may be caused by crushing of casing, friction, static electrical charge, heat, a blow of sufficient energy by heavy equipment, or sympathetic detonation caused by an adjacent UXO. Typical construction activities that can cause inadvertent UXO detonation are percussive and rotary drilling, dredging, jack-up barge leg deployment, excavation by hand or machinery, anchor deployment, jetting, probing or mixing, sheet and percussive piling and bored piling. The main effects of partial or full detonation are shock, blast, heat, shrapnel damage and noise. The effects of the detonation of UXO such as shells or bombs are usually extremely fast, resulting in physical destruction and the effects on the environment.

3.3. Environmental contamination

Detonation or corrosion will also release environmental contaminants. Heavy metals such as copper or zinc from the bomb's casing, lead or mercury from the detonator, organic aromatics (TNT, TNB, RDX and other daughter products) from the explosive charge, white phosphorus or other added chemicals on specifically designed devices toxically for humans [14]. Undamaged UXO casings corrode in the environment characteristically depending on aeration, electrolyte content, pH, moisture, the soil type and amount of soil bacteria in the environment. If the casing is corroded through, the explosive contaminants and heavy metals can be released into the surrounding soils and dissolve in marine or groundwater/surface waters. Environmental damage includes but is not limited to direct toxic effects on organisms, the effects from pressure changes and further the bioaccumulation in the food web (especially in the shore dumping areas), and effects on drinking water resources [15].

3.4. Munitions "made safe"

The HKSAR Geotechnical Engineering Office "Guidance Note on Incidents Involving Explosive Ordnance During Marine Dredging" assures the reader that "the majority of ordnance which were dumped into the sea were made safe prior to their disposal". However, the war-time definition of the term "rendering safe" in military codes of this era only required the munition to be made sufficiently safe for its temporary handling during disposal of the item [16].

The fuzes in these dumped munitions should have been removed, or, at least, made inoperable. In both cases the main explosive charge remains intact, and likely so would any booster charge. The explosive is then exposed to the elements, susceptible to external influences, particularly if impurities have leeched into the casing and have made the explosive more sensitive due to chemical reactions. At the end of conflict in Hong Kong surplus military ordnance were therefore probably made "safe enough" to avoid detonation during disposal, however they could still now be unintentionally detonated.

Military ordnance dumped post-WW2 characteristically represents as much as 90% of all dedicated military ordnance manufactured during the war years. Therefore the quantity of near-shore UXO in Hong Kong waters may be a magnitude greater than ordnance "fired in anger" (in Table 1 for example). The loss of reliable records over time does not make any estimation straightforward.

3.5. Dredging Activity

Over the most recent 30 years, more than 270 million m3 of marine sand has been extracted from the seabed in Hong Kong waters and used as marine fill for Hong Kong reclamation projects [17]. This and other dredging for regular maintenance of shipping navigation channels may also contribute to munitions migration. The presence of these navigational channels will be a control on current flow and direction, and may increase the rates of sediment erosion and accretion, leading to further UXO migration.

Larger UXO dropped in shallow water (less than 12m) may have penetrated and continue to reside some depth below the sea bed. This is almost certainly the case for ten US Mk-13 air-dropped torpedoes (Fig. 3.) that almost immediately became "mudders" – a term the crews used to describe live, undetonated munitions buried in soft ground. The quantity of UXO hauled in fishing nets, displaced by channel maintenance or removed by dredging is not well reported.

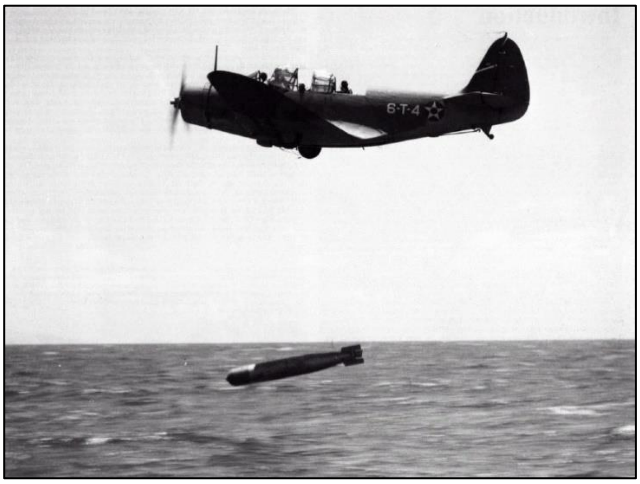

Figure 3. Ten Mk-13 air-dropped torpedoes, armed, undetonated and missing in Victoria Harbour. (Courtesy Gwulo: Old Hong Kong)

4. Environment

4.1. Hydrography

Approximately 70% of the water in Victoria Harbour ranges in depth between 2.5m to 9m. The shipping channels range up to 30m deep [18]. Present day water levels have not changed significantly, however the erosion and accretion of sea floor sediments is a seasonal ocurrence with net gains and losses managed by dredging maintenance.

The harbour is bounded by the Pearl River estuary to the west and the South China Sea to the east. Water deepens in the harbour due east, reaching depths of 25m at Ma Wan Channel, the western coast of Hong Kong Island and Lei Yue Mun.

Direction of seabed current flows affects the transportation process of sediments as well as unburied and partially buried UXO [19]. There are two major seasonal currents. During summer (June and July), the northeast flowing Hainan Current, associated with the Southwest monsoon, dominates. In winter (October to March), Hong Kong water is mainly affected by the southwest flowing Taiwan Current (South China Coastal Current) which is also mixed with Kuro Shio currents, associated with the Northeast monsoon. During spring and autumn (April to May, and August to September), a transition between the aforementioned major currents occurs, presenting unstable and reversing current directions.

4.2. Topography and extreme weather

Additional factors affecting water energy and direction including topographic influence and extreme weather. Due to the presence of many islands, currents in Hong Kong water are forced into various narrow channels where flow velocity increases. Extreme weather such as typhoon also affects Hong Kong water, particularly in summertime and within the surf zone.

4.3. Geology

The sea bed is generally covered with very soft to soft recent deposits and interrupted by older igneous rock of Mesozoic era [20]. These superficial deposits vary from discontinuous to lterally extensive mud and sand sheets up to several tens of metres thick in offshore areas. The geological setting is described in Table 3 below.

4.4. Reclamations

In many areas along the coast, reclamation materials have been placed over the superficial deposits. Some of these reclamations are more than 120 years old, others are currently in progress. The significance of these reclamations is that WW2 UXO may be sitting on top of older reclamations, or covered by younger reclamations. UXO burial depth is therefore complicated by reclamation history [21].

Marine sand is often used as fill material for reclamation in Hong Kong. During 1929-1931 and 1956-1959, hydraulic fill [22] and granular seabed material [23] dredged from Victoria Harbour was used to extend Kai Tak.

Table 3. The geological setting of Victoria Harbour [20, 24 & 25]

Seabed Morphology	Series / Age Million of years ago (Ma)	Comment
Hang Hau Formation	Holocene (0 – 0.0117 Ma)	Very soft to soft, grey, structureless clayey silt, with common shells and lenses of fine sand" and "muddy, shelly sand overlain by interbedded sand and clayey silt". Thickness of the formation varies and reaches 60m (maximum) in the southeast of Hong Kong waters.
Waglan Formation	Late Pleistocene (0.0117 – 0.126 Ma)	Interbedded shelly sand and clayey silt and firm, grey, shelly, clayey silt. The thickness increases towards south and east. Confined to the south-eastern waters of Hong Kong with minor younger coastal reclamations
Sham Wat Formation	Late Pleistocene (0.0117 – 0.126 Ma)	Soft to firm silty clays, grey with bands of yellowish mottling, patches of intense mottling with nodules, some thin sand bands, rare shells commonly corroded". The thickness of Sham Wat Formation varies from a few meters at the northern edges of the subcrop to over 40m at its maximum thickness near the Soko Islands.
Chek Lap Kok Formation	Pleistocene (2.588 – 0.126 Ma)	Clays and silts, to sands, gravels and also cobbles and boulders. Variable thickness from a few meters in nearshore areas to over 70m in the south and southeast. Sudden changes in sediment type both horizontally and vertically are common. Most common seabed under reclamation projects.

Other than marine sand, extensive hillside cutting was carried out to supply fill materials (mainly residual weathered granitic rocks) for extension of coastal sites [26]. Fig. 4. presents this historical reclamation history, the footprint of proposed reclamations, areas of intensive WW2 military action, marine geology and the location of ordnance dumping sites and sites gazetted for the extraction of reclamation source sand

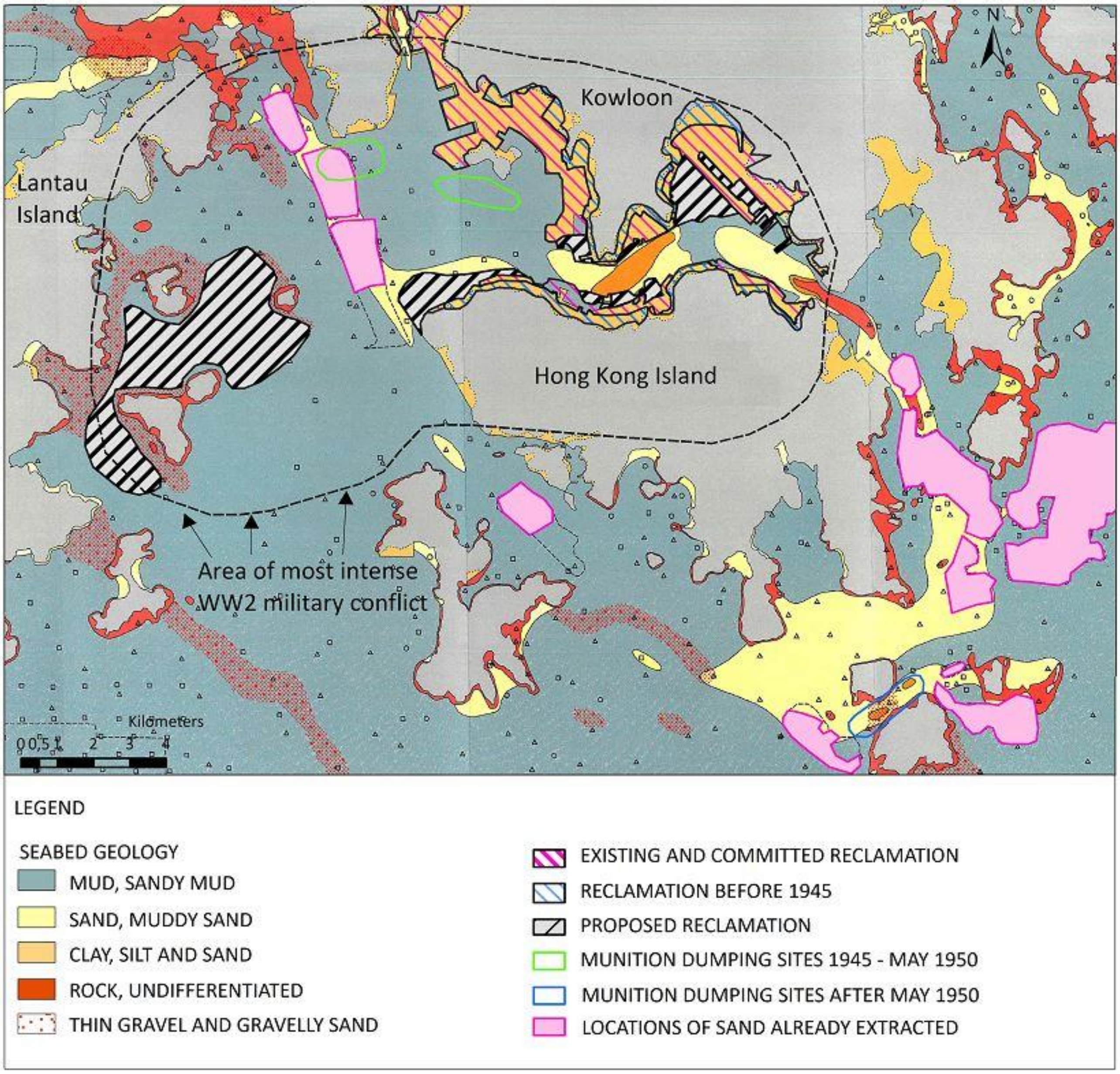

Figure 4. Hong Kong marine geology, UXO prevalence and reclamation activity [5, 8, 20, 24 & 25]

5. UXO Initial Burial Depth Prediction

5.1. Impact on water

Air-dropped and fired munitions enter the sea with significant kinetic energy and may bury deep into the seabed. However, the physical properties of the munition and the environmental conditions limit this potential.

The AN series air-dropped bombs of WW2 era most likely struck water at a velocity of 170 - 186 m/s and a fall angle of 65 degrees, based on aircraft speeds of 320 kph at 5,000 feet altitiude [27]. When a munition moves at high speed through water, the flow separation creates a cavity of air around the body, with full scale tests demonstrating the tail fin will likely break away when hitting the cavitation wall - even with modern weapons [28].

Further experiments at near vertical striking angles resulted in the bomb orientating to almost parallel to the seafloor at water depths ranging from 0.96m to 6.50m [29]. The length-to-diameter ratio of the munition should then determine the final pattern of free fall through the column of water – either flat, straight or spiral [30].

5.2. Initial seabed penetration

Several existing models may be used to predict the burial depth of UXO in the marine environment. These models are sensitive to aerodynamics, hydrodynamics, environment and geology [31] and are useful if the inputs are well defined. To accurately predict the initial penetration depth of UXO in Hong Kong water, further research on the range of impact velocity, profile types of munitions and seabed morphology are recommended.

However the major influences on seabed penetration are depth of water at the strike zone, and seabed morphology. Upon review of the available full scale tests, hydrography and geology, the authors propose the following guidance in Table 4.

Table 4. Initial seabed penetration. WW2 UXO, Victoria Harbour

Water depths (m)	Geology	Initial penetration into seabed (m)
2.5m – 6.0m	Very soft to soft mud, sandy MUD	2m – 6m
	Stiff to firm clay, silt SAND	1m – 4m
	SAND, muddy SAND	0.5m – 2m
6.0m – 10m	Very soft to soft mud, sandy MUD	1m – 3m
	Stiff to firm clay, silt SAND	0.5m – 2m
	SAND, muddy SAND	0.5m – 1m
10m – 15m	Very soft to soft mud, sandy MUD	1m – 2m
	Stiff to firm clay, silt SAND	0.5m – 1m
	SAND, muddy SAND	0 - 0.5m
> 15m	Very soft to soft mud, sandy MUD	0.5m – 1m
	Stiff to firm clay, silt SAND	0.5m
	SAND, muddy SAND	0 - 0.5m

Significant penetration into the sea floor may be expected in shallow water and soft soil conditions. In deep water, undetonated munitions will lose almost all their original kinetic energy and will fall under gravity to rest upon, or sink into the seabed. Such items may later migrate across the seabed subject to, amongst other things, their shape, seabed morphology and the marine environment.

6. UXO subsequent reburial

The subsequent burial of UXO is influenced by bottom water velocity, erosion and deposition of seabed sediments.

Undetonated munitions buried to more than 1/2 of their diameter are considered to be immobile in a lacustrine environment. However as bed-level velocities gradually increase the munition will be subject to scour-burial, transient exposure by erosion, equilibrium, frequent exposure and finally mobilization and migration [32]. These processes may be immediate, seasonal or even a longer term phenomena due to climate changes [33].

Modelling of seabed changes post deployment, along with a review of historical records and a detailed understanding of sediment type and hydrography is necessary for further prediction.

6.1. Scour burial

When the exposed part of a partially buried munition can no longer generate sufficient perturbation flow to cause further burial (the Shields number), an equilibrium level is met. When erosion is strong enough, the degree of burial of UXO may be changed. However, it is worth noting that erosion and accretion are slower processes than scour burial, except during storm events [30].

A two-dimensional burial regime map developed by the Institution for Defense Analyses illustrates the relationship amongst the state of burial of UXO and velocity of current flow is presented as Fig. 5. Note that D is the munition diameter, and UXO are fully buried when d0 > D and partially buried when 0 < d0 < D.

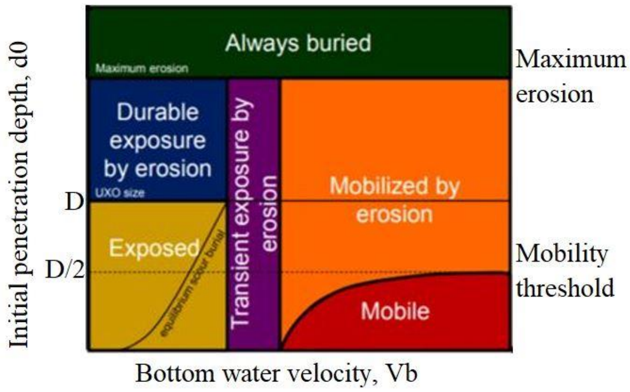

Figure 5. Scour-burial and bottom water velocity (source: Teichman [30])

Amongst the different regions shown in this map, it is worth noting the region of “transient exposure by erosion” which may occur over short term and long term conditions. This means that the munition will be fully buried due to scour burial in the long term even if it is initially exposed. Since erosion and accretion processes may expose the munition periodically, its exposure will only be temporary due to further scour burial.

7. UXO Detection

The UXO risk mitigation process is most efficient when under the guidance and control of a specialist who can carry out the full spectrum of UXO risk mitigation services.

This ranges from the identification of potential risk through to the ultimate issuance of a clearance report and/or certificate (Fig. 6.). The visual identification process often results in many false positive identifications, with a low percentage proving to be UXO. Many turn out to be ferrous material such as old anchors, lost-at-sea metallic debris, steel wire rope and other fishing gear.

However, the UXO identification serves a dual purpose of allowing these non-UXO targets to be identified.

Geophysical survey should only be conducted after a comprehensive desk study of the area. Non-invasive geophysical survey techniques do allow large study areas to be covered quickly and the focus should be concentrated on the identification of targets and areas of interest. The risk of uncontrolled detonation during geophysical survey is low. However, some detectors such as radio frequency devices can detonate radio or variable time fuses and electrical blasting caps.

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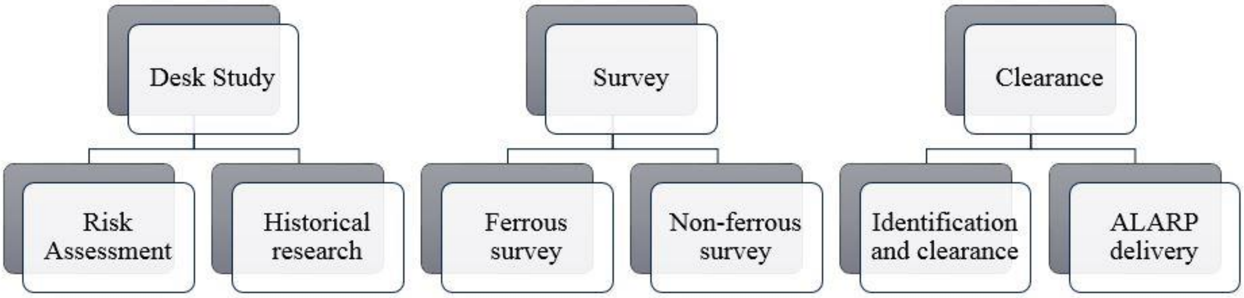


Figure 6. UXO risk mitigation procedure

7.1. Geophysical survey

In selection of survey type, the objective is to choose the detectable physical property that can distinguish UXO from the surrounding environment. There are four phases of field survey programme and several combinations of sensors and carriers suitable for Hong Kong waters.

7.1.1. Phase 1 - Bathymetry

Water depth and large underwater obstructions within the research area are assessed. The bathymetry map obtained is used to plan the route of sub-towed sensors in Phase II and avoid equipment damage. Multi-beam echo sonar carried by small boat is preferred for Hong Kong waters.

7.1.2. Phase 2 – Search, classify, map

UXO in Hong Kong is characterized by shell appearance, ferrous properties and acoustic impedance contrasts with the mud and sand environment. After ferrous items have been swept, a non-ferrous survey is recommended. Data processing and interpretation is critical to the success of these surveys, and relies heavily on the experience of UXO technicians to avoid overlooking UXO and reduce false positives at the same time. In this phase, sub-towed sensors may be used for various purposes. After the sensors and carriers are selected, a geophysical prove-out is performed to determine whether the selected geophysical investigation approach will work on the study area. A list of Contacts of Interest (COI) with the highest probability is prepared for further identification in Phase 3.

- Side-Scan Sonar
  Side-Scan Sonar (SSS) is used to efficiently create an image of the sea floor with good resolution and swath coverage, helping us to identify features that may be sea-floor UXO.

- Magnetometer
  For buried UXO, a magnetometer is used to detect the ferrous property of UXO but is not suitable for non-ferrous UXO. In order to distinguish ferrous objects from soil, we have to understand background mineral content of the ground to be aware of natural ferrous objects like magnetic black sand (Fe_3O_4) and pyrite (FeS_2); estimate the buried depth, target weapons type and size to choose suitable sensors, frequency and sensitivity for survey [34]. However, limited information can be obtained from this method. Firstly, magnetometer is not reliable to distinguish between UXOs and metal debris due to their similar ferrous properties and false positives may be expected.. Secondly, the received signal is affected by the weapon type, size, amount and also the buried depth. So, the signal intensity can give us hints on the target property, however, any interpretation without further evidence is unconvincing.

- Sub-bottom profiler
  By deploying the Sub-Bottom Profiler (SBP), we can obtain the buried object size and depth from the image and make interpretation with more confidence by their acoustic impedance difference. The SBP detects objects using an acoustic wave, however the data is sensitive to external noises from ship engine or the natural environment. Signal penetration is also affected by the transducer flying height and acoustic source strength. The upper seabed layer in SBP data is often not clear enough for small target detection.

- Electromagnetic Survey
  Electromagnetic (EM) is an alternative geophysical tool to search for non-ferrous UXO, which transmits primary EM wave into the soil and detects the secondary EM wave induced by the buried conductive material. Alloy bodied munitions do contain some ferrous metal parts (switches, coils) and it is this material that can be identified using EM.

7.1.3. Phase 3 – Reacquire and Identify

Remotely-Operated Vehicles are sent to the Contacts of Interest for an optical or tactile check of its shape. A three-dimensional SBP system allows further identification of a potential UXO. The information obtained from this phase also helps to decide a feasible remedy action.

7.1.4. Phase 4 – Clearance Check

Avoidance, or removal and disposal are the common remedies for a confirmed UXO. A post-removal check is needed to confirm the location is clear as multiple UXOs may exist at the same location. Remapping using magnetometer and/or SBP is important to improve confidence on UXO clearance.

7.2. Carrier selection

The carrier accomodated all survey sensors and data recording a suitable elevation above the survey object.

The Remotely-Operated Towed Vehicle (ROTV) is our preferred carrier for towed survey in Hong Kong, towed by a vessel with a cable connected to control the elevation and direction during survey (Fig. 7.). The mobility of the vessel and cable controlled ROTV allows the towed array to move out of the way of traffic. Since the vessel engine is far from the sensors, the electromagnetic and acoustic sensor-carrier interference is minimized. ROTV can carry out acoustic and magnetometer survey at 3-5 knots simultaneously with 4-5m swath at water depths of 3-20m, which has balanced performance in comparison with other carriers.

For some site specific conditions not suitable for ROTV (e.g. narrow channel and heavy water traffic), a Remotely-Operated Vehicle requires less space and less disturbance to the water traffic during survey and is a suitable substitution.

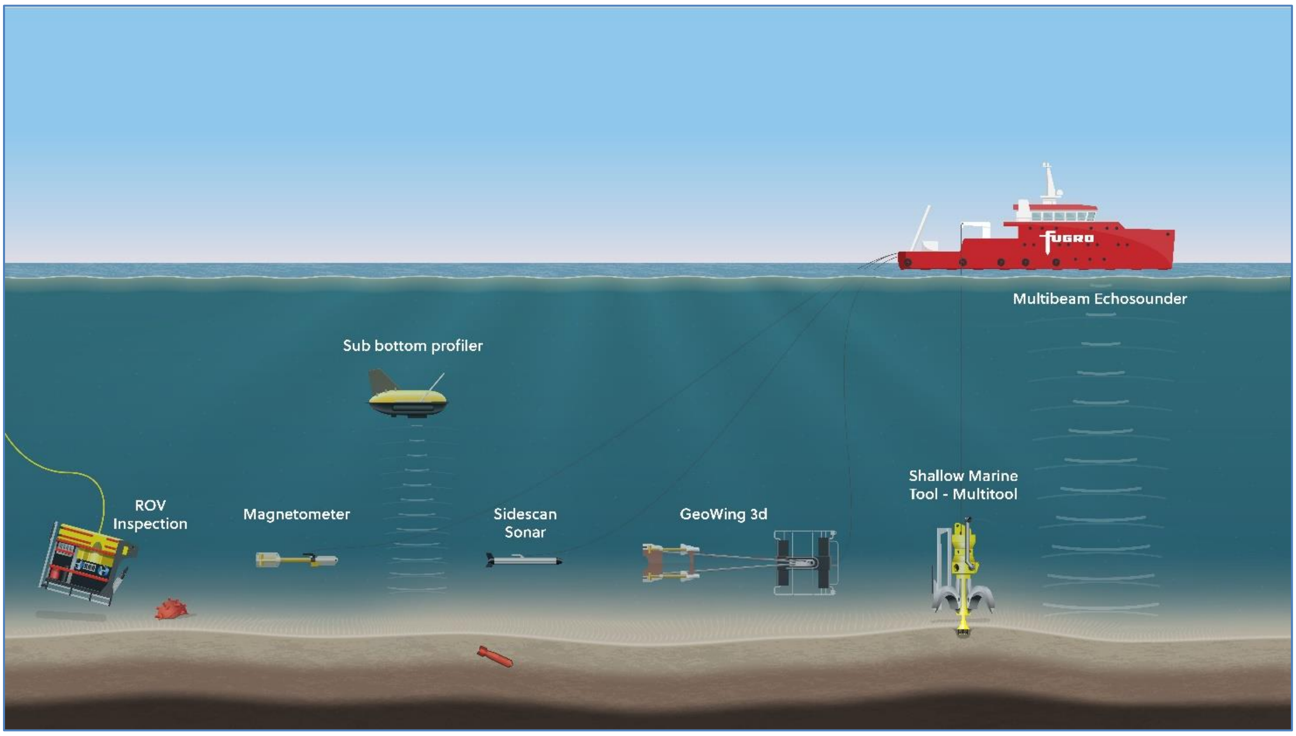


Figure 7. Survey tools

8. Risk management framework

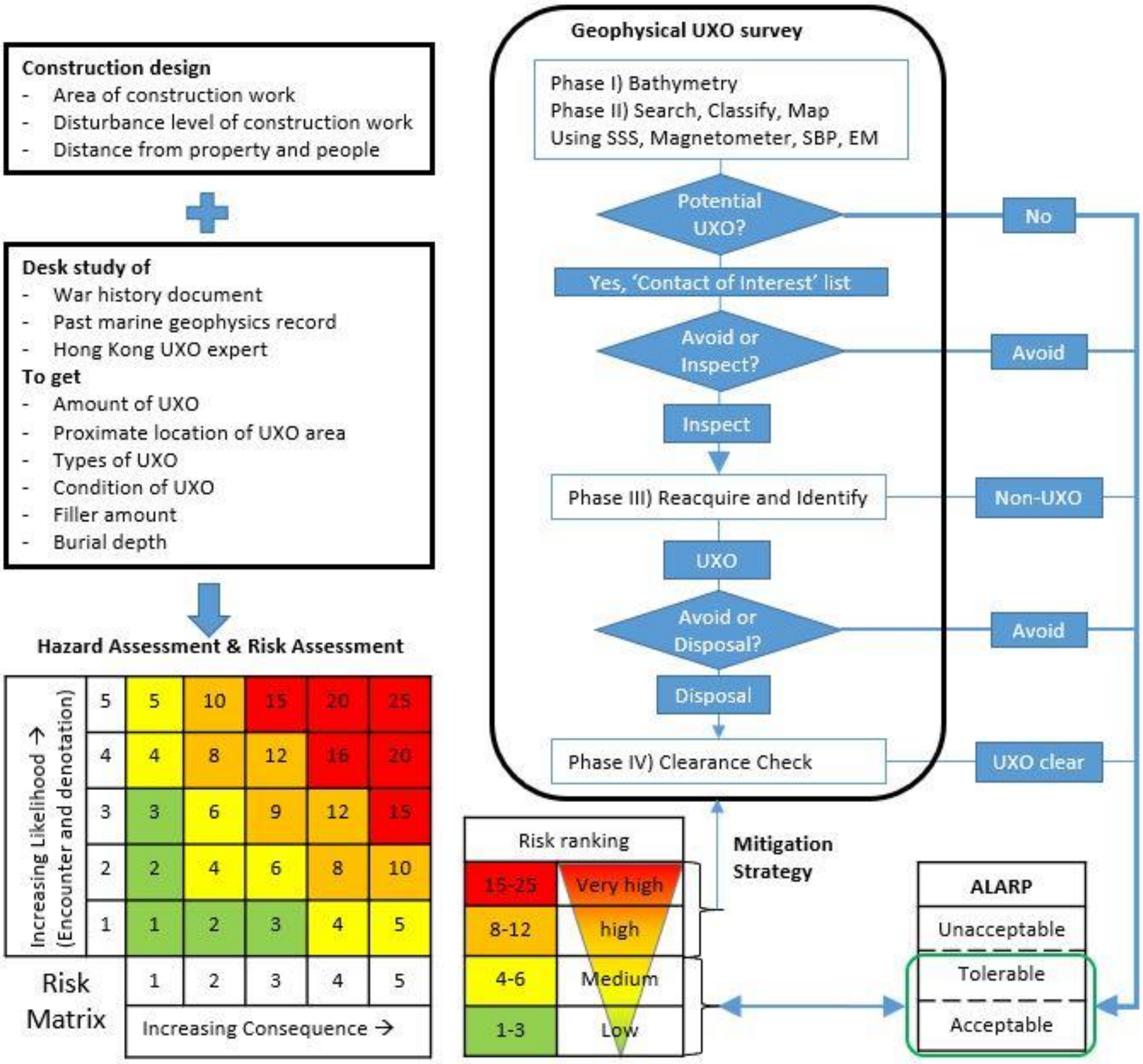
The possession of explosives is highly regulated in Hong Kong (the Firearms & Ammunitions Ordinance, Crimes Ordinance, Chemical Weapons Ordinance and the Dangerous Good Regulations). Other than this legislation, UXO contaminated areas are not managed proactively, but could be by their inclusion in the governments list of Scheduled Areas managed by the Buildings Department (under the Buildings Ordinance). Any UXO risk management framework should be prepared with this future possibility in mind (Fig. 8.).

The probabality of disturbing any UXO increases with any construction or other invasive activity in an area known to be contaminated. The consequences of an uncontrolled detonation will depend on the energy released from a blast, and its proximity to person, the environment or other asset.

Construction activities that carry unacceptable risk should be managed with a mitigation strategy until the risk is lowered to a tolerable level – either by lowering the likelihood or consequence.

UXO surveys can effectively lower the risk, however, it is necessary to choose suitable methods that are proven effective and minimise the risk of uncontrolled detonation during survey. The method of handling the UXO needs to be well documented and the actual handling of the UXOs should only be carried out by approved persons

After any mitigation strategy is concluded, a hazard and risk re-assessment is necessary, until all the unacceptable risk becomes tolerable or acceptable. Construction site activities may then resume.



Increasing Likelihood → (Encounter and denotation)	5	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5
Risk Matrix		1	2	3	4	5
		Increasing Consequence →				

Figure 8. Risk Management Framework. Hong Kong Marine UXO
Figure 9.

9. Conclusions

There may be 800 to 1,000 tonnes of WW2 era UXO and 36,000 tonnes of dumped WW2 era munitions on, or buried beneath the sea floor in Victoria Harbour and surrounding waters. Geological processes and human activity have likely transported some of these, so that present day locations are unknown but widespread. They remain dangerous and present a significant hazard, especially to marine construction activities. Modern geophysical survey technology exists to manage this risk, and is proposed as part of a risk management framework.

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