Petrolheads: Managing England's Early Submarines

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English Heritage, the UK Government's adviser on the historic environment of England, has over a decade of experience in the management of shipwreck sites. This experience is largely based on managing change to the remains of sunken wooden vessels which allowed for the publication of online guidance on pre-Industrial ships and boats in spring 2011.

However, in order to begin to understand the management requirements of metal-hulled ships and boats, English Heritage has commenced a programme of research, investigation, analysis, and non-destructive testing on the remains of two protected early submarines; the Holland 5 and A1.

Utilising an ultrasonic thickness gauge for the first time as an archaeological management tool in British waters, English Heritage plans to better understand the deterioration of metal shipwreck sites so as to manage the recent past for the future.

Introduction

English Heritage has over a decade of experience in the management of historic shipwreck sites. This experience is largely based on managing change to the remains of sunken protected wooden warships (such as HMS *Colossus*, sunk 1798) and armed merchant vessels (such as the seventeenth century Swash Channel Wreck), which allowed for the publication of online guidance on pre-Industrial ships and boats in spring 2012 (English Heritage 2012). However, for UK territorial waters adjacent to England, 96% of known wreck sites post-date 1840 (with the majority post-dating 1914). Such sites hold different values and historical interests to wooden wreck sites (such as power plant development / composite to steel typologies / diversification of craft) and, of course, 'modern' historical watercraft are largely less than 100 years old and lie outwith the 2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage at present.

English Heritage guidance on post-1840 ships and boats therefore followed in early 2013 (English Heritage 2013) and is relevant to classes of metal-hulled vessels related to forthcoming global commemorations; the commencement of the First World War and the 70th Anniversary of D-Day.

However, in order to begin to understand the management requirements of metal-hulled vessels, an initial programme of research, ultrasonic investigation and analysis on the remains of two protected early submarines (the Holland No. 5 and A1) began off England's south coast during the summer of 2012 This work commenced with the necessity of understanding the condition, stability and integrity of steel hulls of historic wreck sites without causing damaging and increased degradation.

Target Sites: Steel-hulled Submarines

The *Holland No. 5,* and the *A1,* are two very early types of petrol-driven submarine in service with the Royal Navy between 1902 and 1911. The *Holland No. 5* sank in 1912 off Beachy Head while the *A1* sank in 1911 in Bracklesham Bay. Following their discovery during two independent expeditions, statutory protection of the two boats followed respectively in 2005 and 1998.

In response to submarines entering service in foreign navies during the late 1890's, the British Admiralty reluctantly decided that they should acquire some submarine boats for the purpose of evaluating their potential as a weapon. Agreement was made with the Holland Torpedo Boat Company that five of their Holland No. X design would be built at Vickers Sons & Maxim Ltd at Barrow-in-Furness. The first submarine was launched in October 1901. *No.5* was launched in May 1902. The boats were built in great secrecy and with direct involvement from the Holland Company. The Admiralty regarded the boats as wholly experimental and extensive trials were carried out. Many developments were made on the boats and several of these ideas were taken back to the USA. Not least of which was the first application of a periscope to a submarine in order to allow surface vision while the boat was submerged, all previous submarines were dependant on porpoising up and down to view through deadlights. The Holland boats served their purpose well and even before the last of the type was launched the improved class that was to supersede them was already being built.

Once their function was fulfilled, the Navy quickly disposed of the Holland's. *No.4* had foundered in 1912, but was raised and expended as a gunnery target, and all the rest were sold to ship breakers. *No.5* foundered on 8th August 1912, while under tow to the breakers yard and lies at a depth of *c.*30m on an even keel. In 2012, 71 visitors were licensed to dive the site. The hull of *No. 1*, the first of the experimental class, was located and salvaged in 1982 and is displayed at the RN Submarine Museum. Due to the nature of their service lives the Holland boats produced a great deal of surviving documentation and photographs; these are now housed in the extensive archive of RN Submarine Museum at Gosport.

Built by Vickers in 1903, the *A1* is the first British designed and built submarine used by the Royal Navy. Although she never saw active service, the *A1* sank twice in her career; the first time (in which all of her crew were killed) was in 1904 after a collision with the SS *Berwick Castle* during exercises. The submarine was recovered soon after and subsequently employed for training and experimental work in anti-submarine warfare. During unmanned trials in 1911, operating under automatic pilot as a submerged target, she was lost off Selsey Bill. The position of *A1*'s sinking was known and the wreck marked but when recovery operations began the next day the submarine had disappeared. Efforts at the time failed to relocate her and were eventually abandoned. It is most likely that the submarine was only partially flooded when she sank, and the remaining buoyancy in the hull allowed the strong tides that run around Selsey to move the wreck some five miles away to where she lies today at a general depth of 9m. She was discovered again by a fisherman in 1989 and sold by the Ministry of Defence in 1994. In 2012, 73 visitors were licensed to dive the site. Further historical and archaeological detail about both submarines is available from the online National Heritage List for England.

The two submarine boats were chosen for study, for they lie relatively close together in the same sea area of the wider English Channel; previous investigations and damage have been restricted owing to their protected status and, more importantly, information on their construction and hull-thickness was readily available from naval historical records.

Non-destructive Testing

Non-destructive Testing (NDT) comprises a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage.

Ultrasonic thickness gauges are especially useful for non-destructive measurement of thickness testing, particularly where access is restricted to one side of a hull only. These gauges are employed in many industrial applications around the world and were used, for example, in 2003 to measure the hull of the designated dangerous wreck SS *Richard Montgomery* in the Thames Estuary. Here, measurements were taken at 7 m intervals, from positions: 1 m above seabed level, 600-900 mm below deck level, and 300 mm inside the gunwales on the deck (Maritime & Coastguard Agency 2003).

As Ultrasonic thickness gauges listen for echoes, and can measure virtually any material such as plastics, metals, and internally corroded materials, they are ideal archaeological tools. However, fundamental to the success of direct thickness measurement for assessing the current condition of a metal shipwreck is knowing what the original metal thickness was at the time of sinking. This enables the total metal loss to be calculated, and provides a baseline for assessing a sites' stability or deterioration. Both the *Holland No. 5* and *A1* are built out of steel (an alloy of iron and other elements) and a naval publication from 1979 provides the best summary account of the designs of the two classes of submarine. Here, records of the Director of Naval Construction (DNC) show that hull plating on both the *Holland No. 5* and *A1* was 7/16" (11.1 mm) thick.

Previous Work

In 2009/10, during investigations submitted in partial fulfilment of the requirements for the Degree of Master of Science, post-graduate student undertook a licensed *Investigation into Corrosion on the Holland 5 Submarine* (Harwood 2010). Utilising a Cygnus 1 Diver Ultrasonic Thickness Gauge (UTG) was used to collect four measurements from the post side of the submarine and three from the starboard side. The readings appear to have been taken through concretion and were not accurately located to enable repeatability. However, successful readings were taken which ranged from 5.6 mm at the port quarter to 11.7 mm at the starboard beam.

Corresponding measurements were taken on the *Holland No. 1*, which gave differing thicknesses. This can be explained, as concretion has been removed from the *Holland No. 1,* giving access to exposed hull plating.

However, Harwood had proposed an innovative proposal on which to develop repeatable UTG testing of metal-hulled shipwrecks.

UTG Equipment

A Cygnus DIVE underwater UTG was acquired to enable planned research owing to its ease of use and portability (Figure 1). Rated to 300m depth, the Cygnus gauge can be worn on a divers' forearm, enabling a valuable free hand when working underwater. Working on a pulse-echo principle (whereby the probe transmits a short ultrasonic pulse and receives the returning echoes), the probe frequency of 2.25 MHz provides a measurement range of between 3.0 mm and 250 mm. The probe itself was pre-calibrated to match the velocity of sound through mild steel; 5920 m/s.

Importantly, the Cygnus DIVE provides an accuracy of 0.1mm when calibrated and has a data logging capability.

Figure 1. The Cygnus DIVE UTG sits comfortably on a divers' wrist (courtesy M. Hamilton-Scott).

Shipwreck Corrosion

The major factors which affect the corrosion rates of metal shipwrecks in seawater, can be summarised as:

1. The type of metal used for the ship construction (the type of iron or steel);
2. The presence or absence of non-ferrous metal fixings or fixtures, which could inhibit or promote corrosion of the shipwreck;
3. Seawater salinity, where an increased concentration of chloride ions promotes corrosion;
4. Dissolved Oxygen in the water, where an increased concentration of oxygen in the water promotes corrosion;
5. Temperature, where increased temperatures promote chemical reactions, and therefore corrosion;
6. Water movement around the site, where increased water movement affects salinity, dissolved oxygen and water temperature and therefore corrosion;
7. Marine growth, where increased marine growth can create a protective barrier between metal and seawater, thereby inhibiting corrosion.

However, salinity, dissolved oxygen and water temperature were not recorded as fieldwork was, at this time, aimed at developing a methodology for UTG testing.

Underwater Inspection & Methodological Development

Fieldwork was undertaken in May 2012, using surface-supplied diving equipment. The breathing gas was air and atmospheric conditions were fair. Bottom time on the *Holland No. 5* was limited to around 25 minutes and for the *A1* time increased to a maximum of 88 minutes. An acoustic positioning system enabled accurate recording of the location of each measurement.

It was uncertain as to whether the Cygnus DIVE would be able to measure through corrosion product and concretion on the *Holland No.5* and *A1*. To test whether any measurements taken through concretion

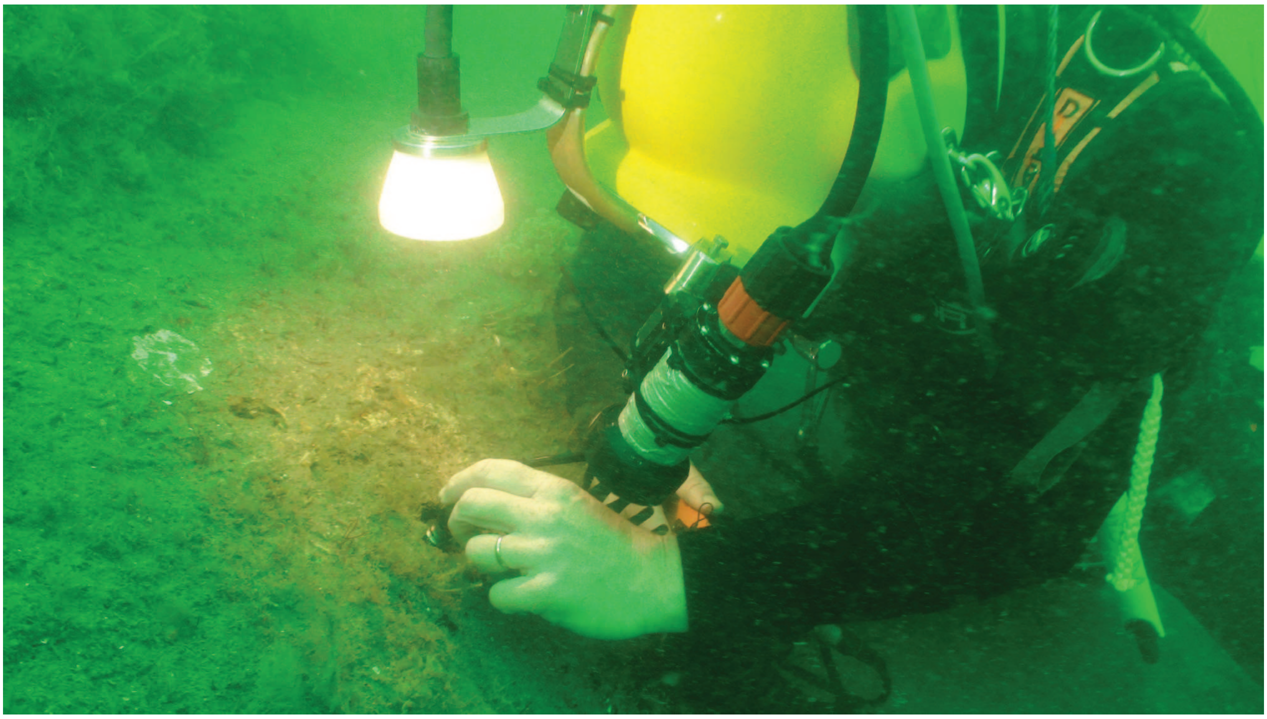

FIGURE 2. USING THE CYGNUS DIVE UTG TO MEASURE THE HULL OF THE A1 SUBMARINE (CROWN COPYRIGHT).

or corrosion product were accurate it was planned to remove concretion and take thickness measurements against bare metal, in addition to through concretion.

Furthermore, it was uncertain how the gauge would react to heavily corroded metal, as the operating manual suggested that the uneven surfaces created as a result of corrosion would 'cause the ultrasound echo pulses to scatter and be absorbed. The ultrasound will be reflected from multiple points as there is no one true metal thickness' (Cygnus DIVE Operation Manual). The operating manual suggests the best option is to slowly move the probe around the area of interest to locate areas of least pitting where a reading may be achieved.

The removal of any corrosion product or concretion from the test sites would reintroduce seawater to the metal and potentially increase localised corrosion if left exposed. In order to reduce any potential damage or destabilisation of the metal by such exposure, the removed concretion was replaced with a non-toxic aquatic epoxy putty as soon as thickness tests were completed. Surex Aquastick was selected for use as this product comes in a rod form with the curing agent encapsulated in the base material, which is a contrasting colour. When the two parts are mixed together the epoxy turns from aquamarine to white and can be used in fresh and sea water environments. The working life of Aquastick is 20 minutes at 20°C, its shrinkage is <1% and its compressive strength is 84 N / mm2.

It was also noted that a number of site specific factors were identified which could affect metal thickness readings on the *Holland No.5* and *A1* at specific measurement locations. These factors can be divided into those which can be identified as directly affecting the thickness of metal being tested (primarily ship construction related), and those which might create differential corrosion rates and therefore variations in metal thickness (primarily environmental). Factors identified as directly affecting metal thickness included:

1. The original 'as built' thickness of the hull plating;
2. The location and nature of hull plating joins;
3. The location of internal frames;
4. The location of external or internal fixtures and fittings, which could affect either the direct thickness of metal in a specific location;
5. Direct damage to the shipwreck hulls, such

as knocks and scrapes caused, for example, by anchor or beam trawling equipment.

The selection of thickness measurement locations, and the design of the methodology was focused to counter any potential variation in metal thickness around the ship, and the possibility for one off, non-representative thickness measurements.

Finally, In order to ensure that measurements were repeatable and indicative of the thickness of the hull in a particular area, four measurements would be taken at two points at each test location, approximately 100-200 mm apart. Two measurements would be taken through the concretion, as it was unclear as to whether the Cygnus DIVE gauge could successfully take measurements through concretion. The concretion would then be removed at these two positions to enable two further measurements on bare metal. It was hoped that this approach would identify any variations in thickness caused by differential corrosion across hull plating, or the accidental location of internal/unseen metal fixtures or fittings such as framing.

Results

Upon inspection underwater, the hulls of both boats were observed to be covered by a layer of concretion (a hard compact mass of corrosion products from iron combined with seawater) colonised by soft marine growth (which for the *Holland No. 5* comprised anemone (*Actinothoe sphyrodeta*) and a variety of seaweeds while seaweeds, anemones and hornwrack (*Flustra foliacea*) were present on the *A1*). For the test areas on each boat, marine growth was cleaned back with a wire brush exposing a 'clean' corrosion surface some 200 mm by 100 mm.

A number of attempts were made to take thickness measurements through the concretion, but the gauge flashed readings between 5.5 mm and 15 mm and no consistent measurements were recorded. A small disc of concretion was therefore removed using a hammer and 20 mm chisel to expose solid metal of the hull. Typically, a circular disc *c.*5 mm thick was removed. The probe of the Cygnus gauge was then held against the exposed steel hull to measure its thickness (and repeated a number of times to confirm the reading) (Figures 2 and 3) and the cavity was made-good with epoxy putty.

Investigation on the *Holland No. 5* was purposely limited to a single reading of 6.5 mm, while readings on the *A1* of 5.6 mm, 5.7 mm and 8.4 mm (against a known 'as built' thickness of 11.1 mm) demonstrate potential variability of hull thickness. These measurements show the need for numerous readings to be taken across a hull to identify erroneous readings and thickness variability in order to locate areas of instability.

Conclusion

From a methodological point of view, the work on the *Holland No.5* and *A1* established that the Cygnus DIVE gauge is capable of taking metal thickness measurements on historic shipwrecks, although see below for further discussion of the actual measurements. Divers found the DIVE gauge easy to deploy and turn on underwater, although some of the divers found that wearing the gauge on the wrist was workable, and others preferred to hold the gauge. The wrist strap was far too big for some of the divers, and a lanyard was used to secure the gauge to

Figure 3. The Cygnus DIVE UTG display, showing (clockwise from top right) thickness reading (8.5 mm), previous logged measurements, echo-verification bars and battery level (Crown Copyright).

the diver instead. The gauge display was easy to read and clearly displayed any verifiable measurements.

Divers found that in some Test Locations the probe needed to be moved around a little to achieve a verifiable measurement, which is likely to be a result of corroded surfaces. As the probe is relatively sensitive to uneven surfaces, it was unpractical for the area of removed concretion to be limited to the *c*. 25 mm of the probe head as originally intended. Instead, larger holes (*c*. 40 mm – 60 mm) were made to find a point at which the probe was able to take a verifiable thickness measurement. One diver noted that an air bubble was present on the probe head, which was preventing measurements being taken. While the probe head membrane is secured with a 'Knurled Ring', it seems that it is relatively easy to catch the edge of the polyurethane membrane, especially when trying to take measurements on rough concretion surfaces, and allow a water/air bubble between the membrane and probe head.

Future visits to the sites of the *Holland No. 5* and *A1* submarines will assess how well the epoxy putty 'repair' is performing and will also commence a programme of temperature recording utilising visiting divers. It is anticipated that salinity and dissolved oxygen measurements will also be recorded in a future research programme in order to fully understand the impacts of corrosion on the two boats.

Utilizing an ultrasonic thickness gauge for the first time as an archaeological management tool in British waters, English Heritage has, with its partners, been able to develop a diver-based methodology to monitor metal hulls of historic wreck sites. This will allow us to implement a programme of active heritage management measures where sites are at risk so as to manage the recent past for the future.

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