Annex G
Scoping Paper

Potential For Differential Corrosion Arising From The Impact of the Divers Shot Line

Site stabilisation for AE2 in the Sea of Marmara following the MAA

Background

During the Maritime Archaeological Assessment of the submarine AE2 and its immediate environs, the support vessel *Detek Salvor* was moored with a set of four anchors to locate the diving platform in close proximity to the submarine. This arrangement was essential to maximise safe deployment of divers and sensing devices such as the Remote Observation Vehicle (ROV) and physical environment measuring devices associated with determining the temperature, salinity and dissolved oxygen on the site. During the night of 13 September a storm caused the *Detek Salvor* to drag its moorings and the 2-tonne concrete anchor block for the shot line, which was attached to the support vessel, moved and "bounced" across the submarine. The percussive action of the weight caused mechanical removal of a large section of concretion from the surface of the submarine and also caused some of the rivets to spring. This accidental damage allowed divers to measure the metal thickness of the submarine in this location, using a hand held ultrasonic device as well a series of ultrasonic measurements were made by the ROV unit. Owing to difficulties in relocating the vessel and due to changes in the turbidity of the site, it was not possible to obtain any corrosion potential measurements on the metal in the immediate or general vicinity of the areas that had been deconcreted. Concluding operations involved a return of the site to its pre-disturbance condition and all markers and other devices associated with the survey were removed.

Issue

Damage to the protective concretion results in direct access of the dissolved oxygen, measured at 2.7 ppm at 16.5°C on site, to the corroding metal and this in effect amounts to a short circuit in the corrosion cell. After years of immersion in seawater, marine iron becomes covered with an intimate mixture of corrosion products and marine growth and debris. This concretion layer causes physical isolation of the anodic and cathodic parts of the corrosion cell, with oxygen reduction occurring on the outside of the concretion seawater interface and metallic corrosion or anodic reactions taking place in an essentially anaerobic microenvironment underneath the concretion. The circuit is completed by electronic conduction of the current through the corrosion and concretion matrix. Once the concretion has been breached, the acidic liquid iron corrosion products interact with the surrounding seawater and voluminous amounts of red-brown iron oxy-hydroxides begin to cover the surface and provide some protection until the marine organisms can once again colonise and begin the encapsulation process. This stage of the process can take several years and during this period the object suffers from accelerated corrosion, which naturally leads to loss of archaeological values.

Quantification of the damage

Without the post disturbance data it is difficult to assess the impact of the deconcretion of the section of the submarine. Relevant observations that can be made by looking at data from a number of other shipwrecks and sites. When the shank of the best bower anchor from HMS *Sirius* (1790) had a 500 cm^2 section of concretion removed the monitoring of the voltage showed that the E_{corr} or corrosion potential had become more anodic by 220 mV which meant that the rate of decay had increased by a factor of 4.7 times during the

72 hour monitoring period after it had been relocated to the Kingston Jetty. Application of an aluminium alloy engine block, a cheap and locally available anode, brought the voltage down by 184 mV within a few hours and by 304 mV at the end of the treatment. An estimate of the final corrosion rate was that it was $^{1}/_{6}$ of the original *in-situ* rate of decay. It should be noted that the *Sirius* anchor was in turbulent water at a depth of only 1.5 metres. Based on the site conditions in the Sea of Marmara, a 220 mV anodic shift in the E_{corr} of AE2 would have resulted in an increased corrosion rate of 4.4 times.

Localised damage on the wreck of the *Fujikawa Maru* (1944) in the Federated States of Micronesia, Chuuk (Truk) Lagoon caused by "dynamite fishing" activities resulted in areas of the concretion spalling and this has resulted in accelerated corrosion of the wreck and loss of archaeological values. Assessment of the impact is difficult to gauge without direct access to metal thickness measurements over time. However it is possible to look at the changes in the mean corrosion voltages of the wreck and also of the pH values, which also reflect the local corrosion rate. Changes in the mean pH between April 2002 and July 2006 indicate that the reported "dynamite fishing" that had impacted on less than 1% of the surface area had resulted in an overall increase of 69% in the corrosion rate. Following this damage, the marine organisms began to colonise the wreck, which is located in equatorial waters at average temperatures of 29.3 ±1.3°C, and the corrosion rate had fallen by 51% of its elevated level within six months as a result of partial re-concretion of the damaged zones. Further "dynamite fishing" activities in early July 2007 resulted in a swing of 95% in corrosion rate. The mean water depth at which the measurements were recorded on the *Fujikawa Maru* was 18.3±2.8 metres, which is significantly shallower than the AE2 site.

Part of the severity of the corrosion impact of accidental concretion damage also depends on the ratio of the anodic to cathodic areas of the metal. Given that the bulk of the submarine is buried in deeply anaerobic sediment, the relatively large surface of exposed metal will result in significant accelerated decay of the boat. Given that the damaged area of AE2 is significantly more than 1% of the surface, it is essential to undertake some form of *in-situ* protection to correct the accidental damage and stabilise the site.

Remediation recommendation

It is imperative that sacrificial anodes are attached to the submarine AE2 in minimise the damage that has been caused by the accidental deconcretion process. Measurements on anchors and cannon that have been treated by anodes *in-situ* on the *Sirius* on Norfolk Island and on the *Xantho* (1872) iron steamship at Port Gregory in Western Australia and on the *Zanoni* (1867) composite ship in Gulf St Vincent in South Australia have established the method of site stabilisation as being very effective. It is recommended that a set of anodes be attached to the bow, the stern and amidships of the vessel to begin the process of *in-situ* conservation and to overcome the damaging impact of the loss of the protective concretion layer. Details of the attachment methods and size of anodes can be developed in consultation with appropriately experienced corrosion protection engineers and naval architects.

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22 November 2007