

# Marine surveys techniques for geo-archaeological research: the case of Naples harbour

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**Abstract** – The Naples bay and, in particular, its harbor, can be rightly considered as precious geo-archaeological repositories. We have investigated the Naples harbor in 2016 with different geophysical survey techniques followed by divers visual inspections. The site location and its high anthropogenic noise have allowed to test the potential and the limits of such methods and the need of design site-specific techniques for both acoustic and magnetic methods.

Some geological insights regarding the pre-historic/historic paleo landscape and the relative sea level oscillations, as well as some archaeological results are also briefly presented.

## I. INTRODUCTION

Marine geo-archaeological investigations are typically based on the integration of different geophysical survey methods that usually precede the visual inspection made by ROV or by divers and the direct sampling of the seabed and its sub-bottom for stratigraphic or geotechnical purposes.

All these methods are ultimately based on underwater acoustics and magnetic techniques and are chiefly aimed at detecting natural or anthropic objects (targets) on or beneath the seafloor and defining the sub-bottom stratigraphy.

Among these the magnetic method is the most sensitive to the anthropic noise especially in industrial sites or densely populated harbors due to the abundance of metallic debris, anchor chains, vessel transit etc. In these cases the level of such background noise may seriously hamper magnetic detection of most targets therefore requiring the design of site-specific and often expensive techniques.

During its recent-most geological history (Holocene) the bay of Naples has been the theatre of hundreds of eruptions, volcano-related subsidence and uplift, sea-level fluctuations and sedimentary dynamics. Its sub-bottom stratigraphy may therefore represent a precious

geological record. The town was settled by Greeks harbor has a millennial history of frequentation since Greek-roman times. These elements made this harbor a huge geo-archaeological repository.

In this article we briefly describe the potential and the limits of the survey methods carried out in the frame of a systematic investigation carried out in the Naples port area on behalf the Port Authority for studying the geo-archaeological potential. Some preliminary geo-archaeological results are also outlined.

The research has integrated a wide range of methods and techniques starting from Geographical Information System (GIS) through the following geophysical surveys: multibeam bathymetry (MBES); side-scan-sonar (SSS); sub-bottom profiling (SBP) and magnetometry until visual inspection by professional divers.

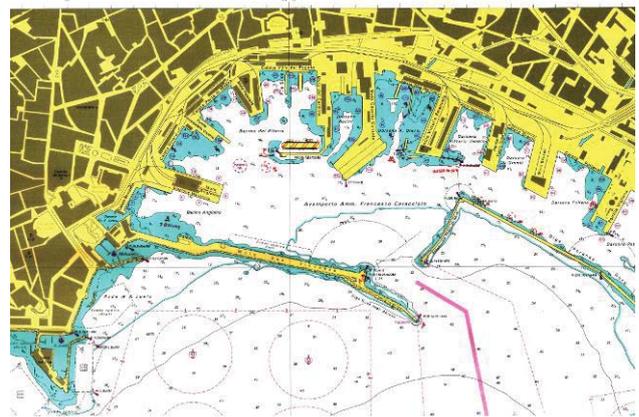


Fig. 1. Detail of nautical chart of the Naples harbour

## II. METHODS

The entire investigation has been carried out in three main phases: 1) Bibliographic study and background information; 2) Bathymetric and geophysical survey; 3) diving survey.

1) The identification of areas of potential historical

wreckages has been supported by the analysis of the “Pianta Topografica della Città di Napoli”, issued in 1828 by the Bourbon Reale Ufficio Topografico della Guerra. This chart was the first one to include topographic and bathymetric data at the same time. This map is particularly relevant because it reports also the location of some wrecks of the Bourbon fleet that were deliberately burn and sunken in 1799 i.e. 29 years before the issue of the document. Original copies of this chart are presently stored in the offices of the Italian Istituto Geografico Militare (Florence, Italy).

The chart has been geo-referenced and compared to modern topography through GIS. The average mismatch measured at buildings corners used as benchmarks resulted in less than 30 m with a mean value of about 15 m. This proves the high standards of topographic techniques based on triangulations that were already attained in the 1<sup>st</sup> half of the 19<sup>th</sup> century.

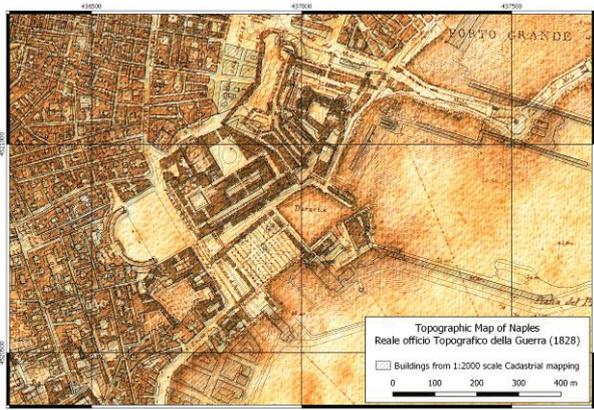


Fig. 2. Extracted from “Pianta Topografica della Città di Napoli e dei suoi Contorni”, Royal Topographic Office of War, 1828. The match with present-day cadastral map shows excellent correlation with mismatches never exceeding 15 m in average.

2) The second phase has included the survey operations carried out on July and October 2016 inside the western sector (i.e. for passenger traffic) of the port area with two survey boats designed for nearshore surveys. The bathymetric survey was carried out through multibeam echosounder covering a total area of about 1.2 km<sup>2</sup>. Subsequently two boxes, supposed to be of geo-archeological interest and respectively located at the port entrance (at 30 m depth) and close to the modern quays (between 2 m and 18 m) have been detailed with SSS and SBP.



Fig. 3. Survey boat designed for shallow water investigations used in the harbour on October 2016.

The vessel positioning and motion sensor (gyrocompass, roll-pitch-heave) were ensured by a DGPS Applanix POS MV integrated system that allowed sub-metric accuracy. Multibeam echosounder and sub-bottom transducer were pole-mounted to the side of the survey boat while side-scan fish was towed at an altitude of 2.5-3m and variable layback depending on depth. Manual layback was adopted based on cable counter being the USBL method (Ultra Short Base Line acoustic positioning) poorly performant in such a noisy and shallow water environment.

A Teledyne Seabat TP20-P multi-beam echo sounder was utilised throughout the survey. With an operating frequency range of 200 to 400 kHz and variable swath coverage selection between 10° and 160° the system was optimised to achieve a balance of resolution to range for individual lines and/or water depths. Due to the relatively shallow water depths, the 400 kHz frequency was chosen. Sea water sound velocity was measured during the survey with a Valeport Mini SVS probe. An average overlap of 30% between adjacent swaths has provided enough redundancy to discard bad data during processing.

Acquisition commenced after complete roll, pitch and heave calibration of the echosounder. The scheduled navigation plan was severely disturbed by the intense traffic inside the port and by the temporary inaccessibility along quays due to alongside cruising ships and ferries. This has required several areas to be infilled in different times leading to extra-processing time for navigation and tidal correction etc.

MBES data processing was carried out in PDS 2000 © software. Tidal correction was applied to data through tidal curves derived from a tide gauge located inside the harbour. An average density of about 50 soundings per square metre was achieved allowing to generate a 0.25x0.25m cell-size Digital Terrain Model (DTM) capable of rendering sub-metric size objects.

The side scan sonar data was acquired using an Edgetech

4125 double frequency (600 to 1600 kHz) tow fish. A range of 25 m per channel, an average flying altitude of 2 m and a variable line spacing from 10 m to 25 m were adopted. Such parameters and an average survey speed of 2 knots have allowed to maintain a spatial resolution in the order of few cm thus capable to detect decimetre-size objects.

The SBP profiles have been acquired with a pole-mounted Innomar SES 2000 parametric system (high frequency: 100 kHz; low frequency: 4-15 kHz) capable of attaining an average vertical resolution of 5 cm. The main scope of the SBP survey was the recognition of the shallow seismic-stratigraphy for geological purpose. SBP data in native format have been converted to SEG Y and then processed with the Geosuite All works © software.

This data hasn't allowed to detect metric or sub-metric size archaeological targets in the sub-bottom due to the overall poor acoustic response of wooden objects coupled to the low spatial resolution offered by lines spaced 10-15m in average. However a couple of SBP profiles across a wooden wreck have allowed to better constrain seabed stratigraphy in the wreck site and its state of burial.

The magnetic survey was also acquired with a towed Marine Magnetics SeaSPY magnetometer but in the port entrance area only. Some trials have in fact shown an extremely high magnetic noise generated by the abundance of modern metallic debris (eg. deadweights, pipes, tyres etc.) and anchor chains in the quay sector. Furthermore this area didn't allow enough manoeuvrability for the vessel and its sensor layback.

3) The dive survey was carried out according standards and procedures of commercial diving. The team included umbilical divers supported by a dedicated barge. Positioning of the barge and of the dive site was allowed by a DGPS system.

The operating water depth was between 10 and 20 m. The barge was fitted with an Atlas Copco QAS14 generator, a Hyperbaric Chamber, two Compressors Bauer and an Amron Command II 2-Diver Air Control System. The divers were equipped with Kirby Morgan helmets, drysuits and 100m long umbilicals. The dive team consisted of four professional divers including two underwater archeologists. Each couple of divers operated for a working time of 90 minutes and was continually followed via audio and video by the onboard superintendent and by a third diver ready to dive in case of emergency.

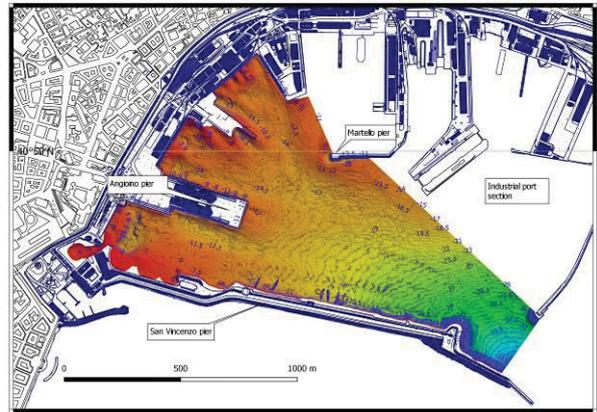


Fig. 4. Multibeam bathymetric survey; depths in metres; contour interval: 0.5m.

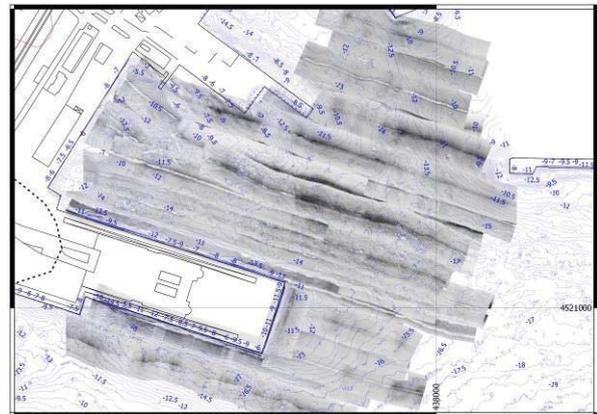


Fig. 5. Example of SSS mosaic, in the Piliero basin between the Molo Angioino and the Immacolatella Vecchia quay.



Fig. 6. Port entrance area surveyed with magnetometric methods.



Fig. 7. Diving equipment onboard the working pontoon.

### III. GEOLOGICAL INSIGHTS AND HOLOCENE PALEO-LANDSCAPE

The joint interpretation of seismo-acoustic profiles and morpho-bathymetry in the harbour, along with the subsurface stratigraphy derived from hundreds of boreholes and excavations carried out onshore in the town (Amato et al., 2009) allow to further constrain the Late Holocene evolution of the coastal landscape.

East of the Monte Echia-Castel dell'Ovo tuffaceous promontory the coastal area at the base of the town's hill was relatively flat and depressed with intermittent lagoonal and alluvial-colluvial sedimentation (Russo Ermolli et al., 2014). The paleo drainage system was controlled by deep incisions engraved into the tuff basement; this ephemeral system was capable of transporting conspicuous volumes of fine sediments during floods resulting in an overall infill and shoreline progradation as proved by seismic stratigraphy in the harbor.

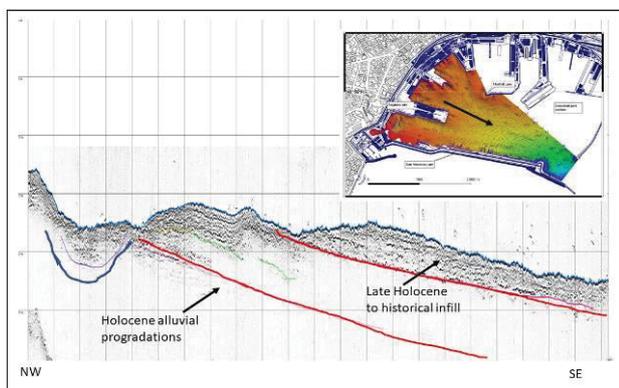


Fig.8. Example of SBP profile across the Piliero basin. Note SE dipping clinoforms of the original prograding coastal wedge, truncated by human activity and draped by latest anthropogenic infill. The profile track is shown by the arrow in the inset.

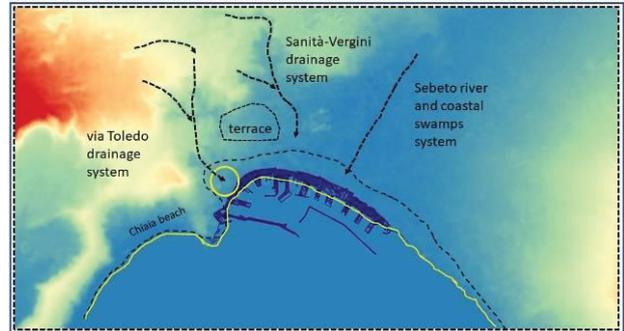


Fig.9. Reconstruction of the paleo-drainage system of the town and coastal aggradation. The dashed line is the inferred Late Holocene shoreline, the yellow line is the present one. Circle is the area of the Greek-Roman harbour.

Therefore, during the Late Holocene and until the first Greek settlement on Mount Echia hill (*Parthenope*, 8<sup>th</sup> century BC) the eastern sector of the present-day urban area was characterized by shallow water sea and local palustrine environments. In this sector the only coastal relief was the Pendino terrace that was later chosen for the foundation of *Neapolis*. It is worth noting that the overall shoreline progradation has been the result of natural (floods) and anthropogenic infill that have counterbalanced a very relevant sea-level rise measured for the last thousand years.

Such relative sea level rise has been evaluated in the order of 3 m or more for the last 2 ka (since Roman times) based on submerged archaeological markers found in the western sector of the town along the Posillipo coast (Aucelli et al., 2019). This value exceeds by almost 2m the standard (1-1.5m) eustatic Late Holocene sea-level rise for stable, non-volcanic areas in the Tyrrhenian region (Lambeck et al., 2011).

Therefore a ground subsidence of almost 2 m has occurred in the Naples urban area since Greek-roman times. Given the proximity to active volcanic areas and the very similar bradiseismic trends measured in the Phlegran Fields it can be suggests that the nature of this subsidence is volcano-related deflation that following eruptive activity.

### IV. ARCHAEOLOGICAL RESULTS: MODERN AND ANCIENT WRECKS

The MBES survey has firstly confirmed along the S. Vincenzo pier the occurrence of 9 modern shipwrecks and a barge that were under seizure around 1970-1980 and were successively sunk into the harbor. Only two of the wrecks lie in upright position the other lying on their sides over a 16m deep seafloor. They correspond to relatively small cargo ships with lengths variable between 30 and 50 m.

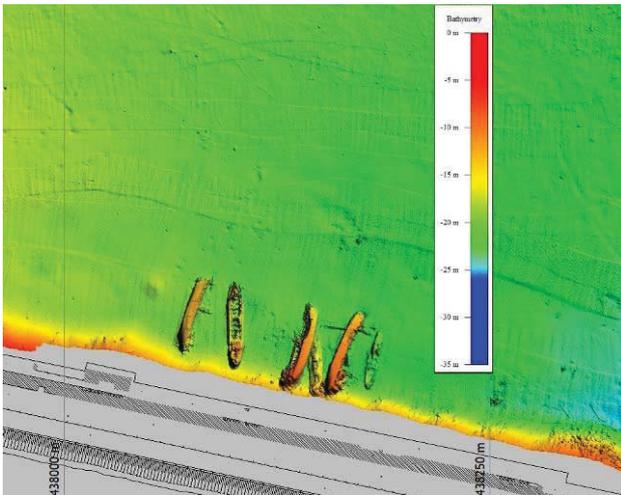


Fig.10. Example of modern wrecks found along the San Vincenzo pier laying at depth of 18-20m. Vessel details are well rendered by this shaded relief bathymetry resulting from a 0.25m DTM.

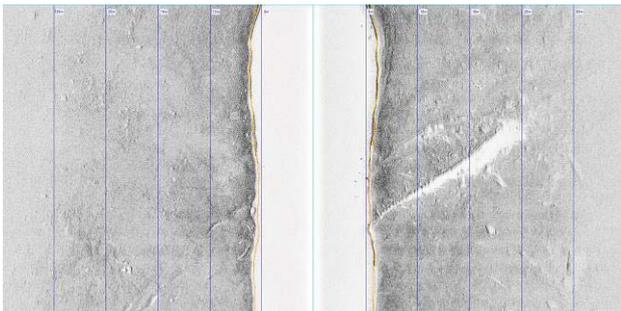


Fig.11. Example of SSS record (600 kHz) over an ancient wooden wreck later identified as the Flora corvette sunken in 1799.

The entire surveyed area is further densely punctuated by hundreds of bathymetric anomalies almost all related to debris, infrastructures etc. which testify the long history of human activity.

In the quay survey area halfway between the Angioino and Martello pier heads, swath bathymetry and SSS data reveal a low-relief bathymetric anomaly at 15.5 m depth

on a seabed heavily marked by debris and anchors scars. The anomaly doesn't exceed 1m in relief and clearly recalls the shape of a shipwreck. This shipwreck has been correlated to the *Flora* corvette that was deliberately burned and sunk on January 1799 by Bourbons prior to the arrival of French troops in Naples (de Alteriis et al. 2019)

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