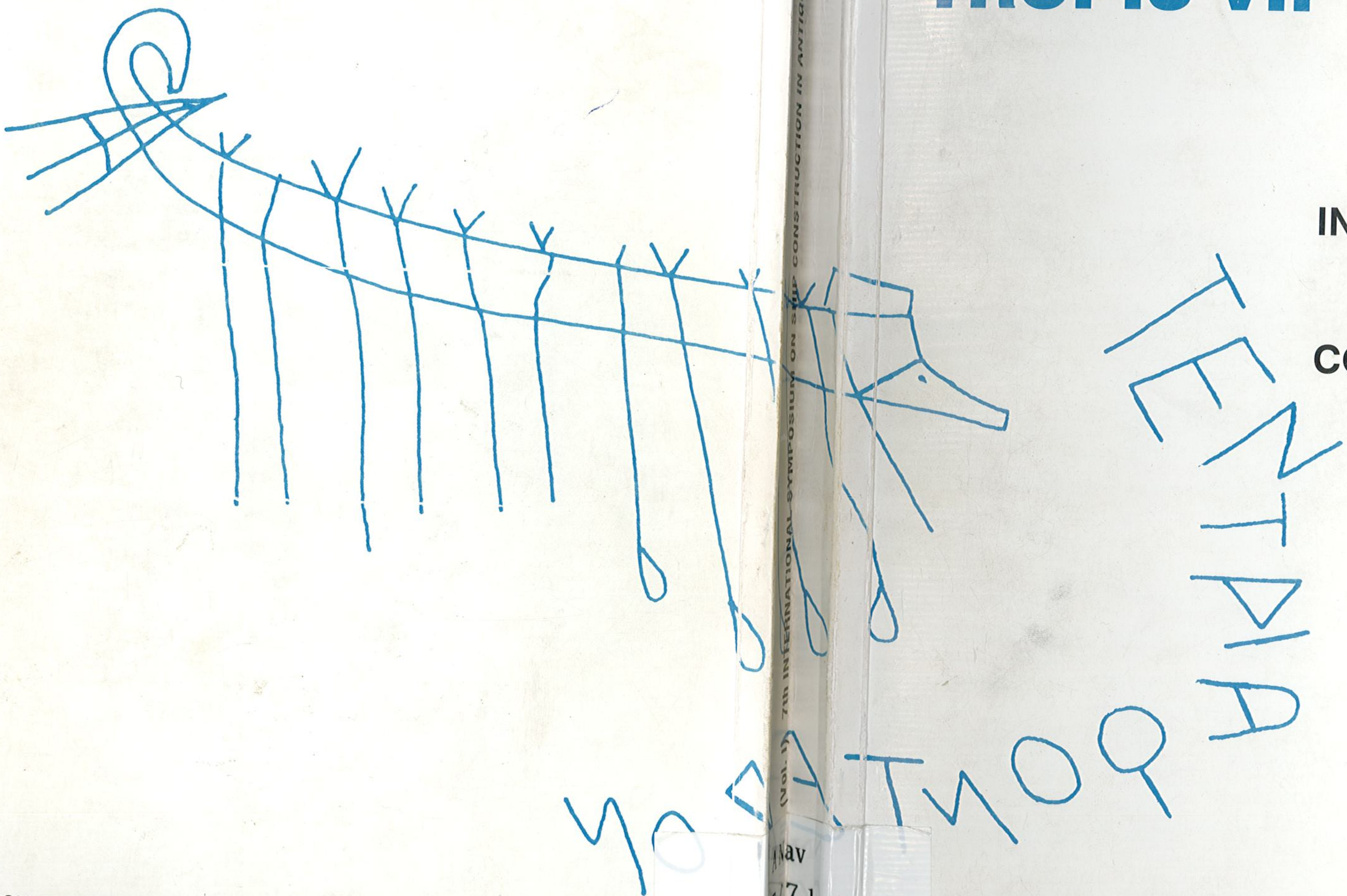
ΤΡΟΠΙΣ VII
TROPIS VII

HELLENIC INSTITUTE
FOR THE PRESERVATION
OF NAUTICAL TRADITION



7th INTERNATIONAL SYMPOSIUM ON SHIP CONSTRUCTION IN ANTIQUITY

PYLOS 1999
proceedings

VOLUME I

edited by
Harry Tzalas

ATHENS 2002

7th INTERNATIONAL SYMPOSIUM ON SHIP CONSTRUCTION IN ANTIQUITY (Vol. I) 2002

ISSN 1105-7947

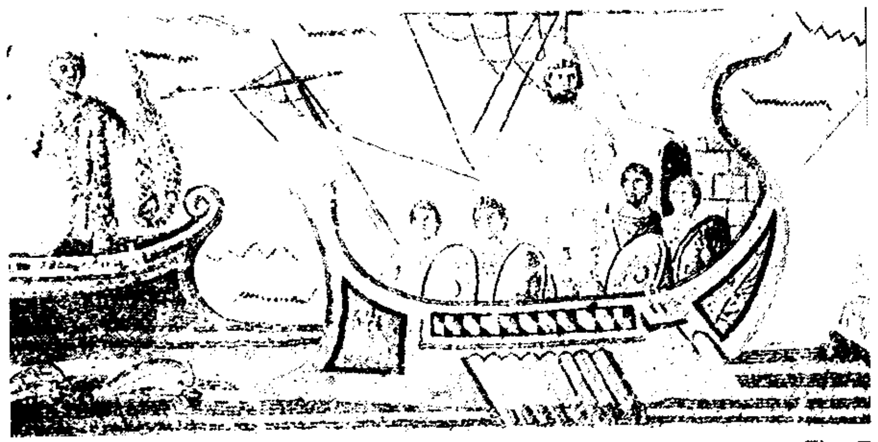


Fig. 7

Fig. 9

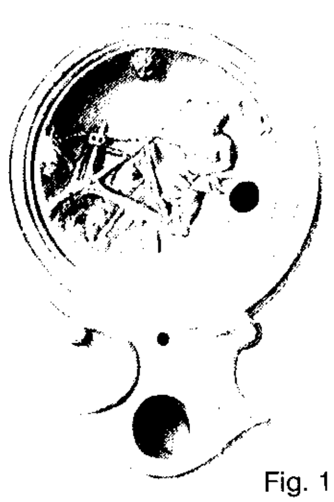


Fig. 11

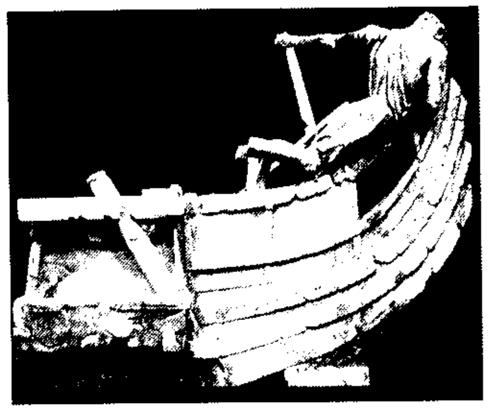


Fig. 10

Fig. 12

HEROD'S CONCRETE BARGES AT CAESAREA MARITIMA: AN UPDATE ON THE RESEARCH CARRIED OUT IN AREA K

Since 1990 Avner Raban of the University of Haifa has directed the study of the unique concrete filled caissons found at the end of the main southern breakwater of the Herodian harbour of Caesarea in Israel (Fig. 1). The extraordinary state of preservation of the concrete and its original formwork has enabled Raban and the author to reconstruct the caissons on paper with a reasonably high level of accuracy (Fig. 2 & 3)[1]. Since 1999 the research has taken on another dimension. Following on from the study of the formwork a parallel and expanding study is looking at the concrete itself.

It has long been recognised that Roman marine engineers were the first to develop hydraulic concrete in the construction of harbours. This happened in the latter part of the 2nd Century BC probably in the vicinity of Puteoli, modern day Pozzuoli[2]. It appears that initially only re-active sands (pozzolana) from the Naples area were used, which is confirmed in Vitruvius' writings (30-20BC)[3]. Later other volcanic sources were used and even crushed pottery.

If, as expected, the source of the pozzolana in the concrete in Area K and other areas of Caesarea's harbour can be shown to have come from the vicinity of Vesuvius as did the raw material for the concrete in Area G (Fig. 1), it would have represented an incredible logistical achievement for the Roman builders[4]. The proportions of the different ingredients lime, sand, pozzolana, and aggregate used in the concretes can be determined by analysing samples. If assumptions are made based on the mix described by Vitruvius and on estimates to the extent of the concrete in the harbour moles at Caesarea, then the volume of pozzolana used can be calculated[3]. There are large concentrations of pozzolanic concrete in areas K, G and U. These sites have been described by Raban as being the remains of "construction islands" and were used as bases from which the breakwaters were extended[5]. The extensions were a combination of rubble, sand infill and double lines of segmented, staggered concrete blocks or pilae. The total volume of concrete used was in excess of 30,000 m^3, which required approximately 13,000 m^3 of pozzolana when allowances are made for wastage, and probably much more if the overlaying structures are included[6]. Shipping this amount of material across the Mediterranean needed extraordinary logistical management and a massive investment in ships.

There is no documentary or archaeological evidence to suggest how this was achieved. It has been suggested that the large freighter wrecked in Area Y at Caesarea, just to the north of the Herodian harbour, was one of the ships bringing in construction material[7]. Is the lack of any archaeological evidence because the pozzolana was either washed away during the wrecking or that it was simply mistaken for silts that filled the ship after its demise? Hohlfelder suggests that grain ships were used on the return leg from Rome; firstly, he argues that they had the capacity, but also Aggripa may have had an interest in the project[8]. Whether the North African grain ships were used or other large freighters, the practical issues involved in transporting this material by sea would be worthy of a study in themselves.

In 1994 samples were taken from the concrete remains in Area K. These blocks were formed within single mission barges or caissons and laid out in a line at the end of the southern breakwater[9]. The first samples taken from this site were simply lumps knocked off the surface with a hammer and chisel. When analysed they did, however, reveal that the structure was formed in layers of differing types of concrete. A non-hydraulic lime mortar and aggregate mix was sandwiched in-between hydraulic pozzolanic rich layers. The fact that the structure contained non-hydraulic material and the presence of un-hydrated lime with cracks radiating from hydrated particles indicates that the material was not placed under water. This suggests that the caissons were dry, and always maintained a freeboard whilst they were being filled[10]. In order to establish the boundaries of the layers with more accuracy and to measure the aggregate spacing a different method of sampling was required. In 1999, with the assistance of the University of Tel Aviv, core samples were taken[11]. The equipment comprised a diamond tipped 50mm diameter, 1m long barrel fitted to an air drill as well as to a pneumatic hammer. The combination of the rotary drill and hammer enabled the barrel to be driven into the hard layers of concrete and aggregate as well as the very soft lime mortar. The use of a compressed air tool was not ideal for this application and, in future, samples will be taken with a hydraulically powered system. This would not suffer the power loss that air systems experience whilst working under water. In addition, a water jet would be fitted onto the barrel jet to flush over the diamond bit and prevent it clogging with a paste from the concrete residue. However, seven samples were successfully taken and analysed by the University of St Andrews in Scotland. These samples were from the outer layer, Core A and inner material, Core B. The inner mass of the middle layer had the consistency of a gravely clay with lumps of limestone and kurkar aggregate. The outer layers, however, had a much harder and consistent matrix. Two

types of analytical study were applied to the samples: X-Ray Diffraction (XRD) and Electron Probe Analysis. Core B samples contained a dominance of quartz and calcite material with small amounts of feldspar, clay, aragonite (possibly derived from shell fragments) and Zeolite. This contrasted with the results from the outer layer, Core A. This core contained a significant amount of Zeolite (probably of volcanic origin) together with Sanidine in a dark matrix consisting of the Zeolites Analcime and Philipsite. Some clay (illite) was also present[12]. The distinct chemical differences between the cores correlated with marked difference in appearance and texture. These tests and analyses confirmed earlier studies that concluded that the concrete blocks in Area K were a mixture of hydraulic and non-hydraulic concretes. However, in order to trace the pumice/pozzolana back to its source, further analysis is necessary. Although the concentration of the main elements of pumice is largely similar regardless of their source, minor and trace elements will vary[4]. The trace elements could be accurately measured by inductively coupled plasma emission spectroscopy or, alternatively the signature of the individual site could be recognised with an isotopic analysis[13]. In this way, a fingerprint database of the volcanic aggregates and sands can be established as a means of determining the source of the pozzolana used.

The methodology developed at Area K for sampling and analysing the concrete will be used in a study of Roman harbour concrete. The study will look at sites across the whole Roman Mediterranean basin from Spain in the west to Israel in the east. It will, hopefully, be multi-national, involving those few specialists who are involved in the study of Roman harbour structures and their engineering. The project will allow us to understand how extensive was the use of pozzolana exported from the Bay of Naples and when alternative sources were substituted. It will cover the whole range of aspects related to the construction of concrete quays, breakwaters and moles. The study will be wide ranging but specifically address the following at each site;

- Why concrete structures were used in preference to other forms of construction
- The methods chosen for forming the concrete
- Details and proportions of the mix [sand/lime/pozzolana (or other reactive material), and coarse aggregate]
- Sources of the mix material (a data-base of source materials will be established)
- How did the designs change across regions and over time?

In 1998 a survey of Area K was commenced with the intent to measure and locate the disposition of the overlaying kurkar blocks and relate them to the concrete remains[14]. This would then prehaps allow proposals for the causes and chronology of the harbour mole's collapse to be made. In 1990 an initial survey was carried out to establish the overall massing of the site, however, the results were inconclusive.

Due to the extremely chaotic nature of the site and often-poor visibility and surge conventional survey methods were inefficient. A trial photographic survey was carried out using "PhotoModeler" software that could manipulate images to construct a three-dimensional computer model[15]. It had previously been used underwater by Nick Strange, and the Nautical Archaeology Society, on the "Mary Tavy" shipwreck in Plymouth Sound[16]. To accurately establish the framework for the images and to produce identifiable points on the amorphous masses, over 300 numbered 10cm diameter yellow plastic discs were fixed to the corners of the concrete and kurkar blocks and 20 datum points were arrayed across the site. Nick Rule's direct survey method, "Web"[17], was used to locate the points in three dimensions. Area K is approximately 40m long (north to south) and 20m wide (east to west) and varies in depth from 1.5m to 10m. Over one thousand direct measurements were taken by volunteers during a two-week period. Each block was individually filmed on video and still images were "captured" and fed into the PhotoModeler programme. The intent was to generate a three dimensional image of each block that could be hung onto the web generated model of the site. Difficulties arose in trying to identify common points or features from one image to another and sometimes this proved impossible. It was concluded that more reference points were needed to allow this technique to work. One method that may prove to be feasible is to drape a weighted net over each block during filming. The net would then be moved from block to block in turn. It is hoped that over the course of the next few seasons another attempt will be made to complete a PhotoModeler survey over this type of terrain. There are, of course, alternative methods available for surveying these structures. These range from measuring each element and feature individually by "hand, eye and tape-measure" (found to be almost impossible to use on this type of terrain) to very high resolution swath bathemetry sonar systems, or even the "SHARPS" (Sonic High Accuracy Ranging and Positioning System) as used on the Dokos project[18]. Area K is an ideal testing site for shallow water three-dimensional mapping. Once an accurate remote sensing co-ordinated survey system is affordable and readily available on the open market (systems are currently available to the Military and Oil and Gas Exploration companies) then studies of numerous harbour sites around the Mediterranean could be carried out. The importance of recording these sites

cannot be over emphasised. So many harbour remains have already been lost to coastal development; time is not on our side[19].

During the 1998 and 1999 seasons Avner Raban conducted a study of the so-called "towers" at the northern end of Area K, the terminus of the main southern breakwater. These structures fit very conveniently with Josephus's description of the towers at the entrance to the Herodian harbour[20]. Until now there has been no question that they were indeed the bases of the towers as described by Josephus. It is now apparent that these structures have been severely dislodged. The east "tower" has been rotated by almost 90° in the vertical plane and its original position cannot be imagined.

Area K is only a very small portion, less than 1.5%, of the drowned ancient harbour of Caesarea Maritima, yet studies have continued there almost continually since 1990 and still it adds to our knowledge of Roman engineering and harbour design.

Christopher Brandon
Pringle Brandon Architects
10 Bonhill Street
London EC2A 4QJ UK

NOTES AND REFERENCES

1 Brandon, C., 1997. The Concrete Filled Barges of King Herod's Harbor of Sebastos. In: (S.Swiny, R. Hohlfelder, & H. Swiny, Ed.), *Res Maritimae, Cyprus and the Eastern Mediterranean from Pre-history to Late Antiquity*. CAARI Monograph Series I, ASOR., 45-58.

2 McCann, A., 1987. *The Roman Port and Fishery of Cosa,* Princeton, p.327.

3 Morgan, M.,1914. *Vitruvius, The Ten Books on Architecture,* Book V, Chap. XII.2.

4 Oleson and Branton's ground breaking research in identifying the source of the pozzolana used at Caesarea will form the basis of future work in studying the development of Roman harbour engineering, see Oleson, J. & Branton, G., 1992, The technology of King Herod's harbour. In: (R. Vann, Ed.), *Caesarea Papers, Straton's Tower, Herod's Harbour, and Roman and Byzantine Caesarea*, JRA Supp. Series No. 5. Ann Arbor, 49-67.

5 Raban, A., 1992, Sebastos, the Herodian harbor of Caesarea: How it was built and operated. In Center for Maritime Studies News. August 1992. University of Haifa.

6 A. Raban, personal communication. The calculated volume of pozzolana can be calculated from an assumed combined length, the concrete structures being approximately 1000 m, multiplied by 4 (the estimated height of the structures in metres), multiplied by 2 (two parallel spinal lines), and multiplied by 4 (estimated average width of the structures in metres). This equates to a volume of concrete of 32,000 m^3

7 Fitzgerald, M. 1994, Chapter VI; the Ship. In (J. P. Oleson, M. Fitzgerald, and A.

Sherwood, Eds.) *The Harbours of Caesarea Maritima, Results of the Caesarea Ancient Harbour Excavation Project 1980 -1985. Volume II; The Finds and the Ship*, BAR International Series 594, Oxford, 163-223.

8 Hohlfelder, R., 2000, Beyond Coincidence? Marcus Agrippa and King Herod's Harbor, In Journal of Near Easter Studies, 59 N0. 3. University of Chicago, 241-253.

9 Brandon, C., 1996. Cements, Concrete, and Settling Barges at Sebastos: Comparisons with other Roman Harbor examples and the Descriptions of Vitruvius, In (A. Raban, & K. Holum, Eds.), *Caesarea Maritima, A Retrospective after Two Millennia*, Brill, 25-40.

10 Brandon, C., 1999, Pozzolana, lime, and single-mission barges (area K), In (K. Holum, A. Raban, & J. Patrich, Eds.), *Caesarea Papers 2, JRA Supp. Series No. 35*. Portsmouth, Rhode Island. 169-178.

11 Dr. Ma'oz Fine, University of Tel Aviv, provided invaluable assistance not only in allowing us to use his equipment, but also providing practical experience in coring underwater.

12 C. Richard Bates of the University of St. Andrews analysed two of the samples and my thanks goes to Martin Bates of the University of Wales who arranged for the work to be carried out.

13 J. Ingham, Technotrade, Harpenden, UK., personal communication.

14 *Kurkar*, the local building stone, is a relatively soft and porous carbonate-cemented quartz eolianite sandstone (see Oleson and Branton 1992: 58-63).

15 *PhotoModeler* is a Windows software package for measuring and modelling real-world objects and scenes through the use of photographs. It has been developed by Eos Sytems Inc.

16 Nick Strange, University of Plymouth, personal communication.

17 Rule, N., 1989, Direct Survey Method and its Application Underwater, *IJNA* 18.2:157-162.

18 Vossyniotis, S., 1992., Dokos: 1990 Campaign, The SHARPS and the Mechanical Equipment, In: (Y. Vichos Ed.), *ENALIA Annual 1990, Hellenic Institute of Marine Archaeology Vol. II*, pp.36-38.

19 Felici, E., 1998, La Ricerca sui Porti Romani in Cementizio: Metodi e Obiettivi, In *Archeologia Subacquea, Come Opera L'Archeologo Sott'Acqua Storie Dalle Acque. VIII Ciclo di Lezioni sulla Ricerca applicata in Archeologia Certosa di Pontignano (Siena)*, 9-15 Dicembre 1996. Pp 275-340.

20 Vann, R., 1989, Area K: Twin Towers West of Entrance Channel. In: (A.Raban, Ed.), *The Harbours of Caesarea Maritima, Results of the Caesarea Ancient Harbour Excavation Project, 1980-1985. Vol. 1 part (I)* BAR International Series 491. Oxford. 149-151.

ILLUSTRATIONS

1. Site plan of Caesarea Maritima in Israel.
2. North east corner of the well preserved caisson K5.
3. Reconstruction of a K type caisson.

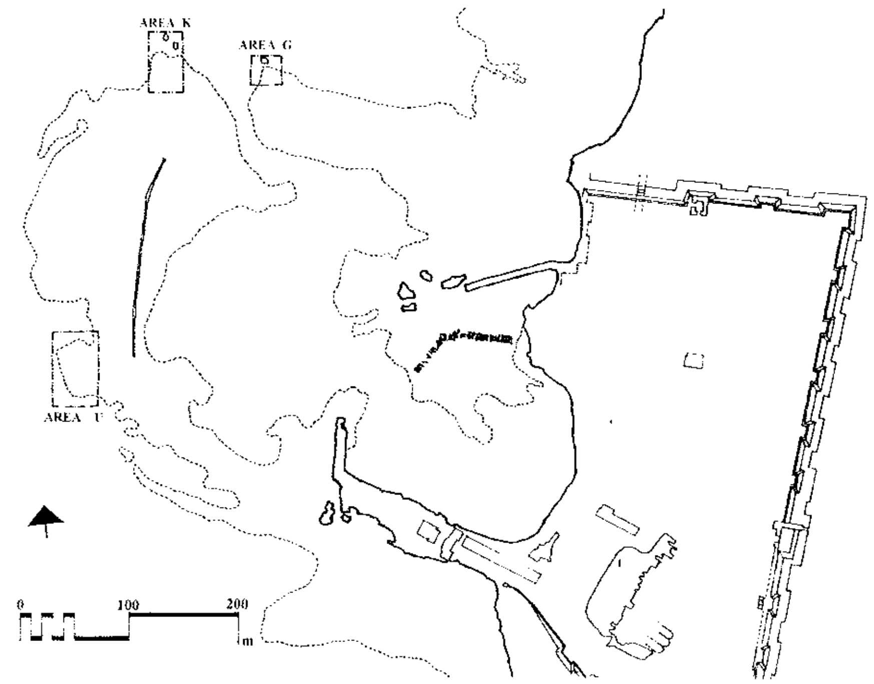


Fig. 1

Fig. 2

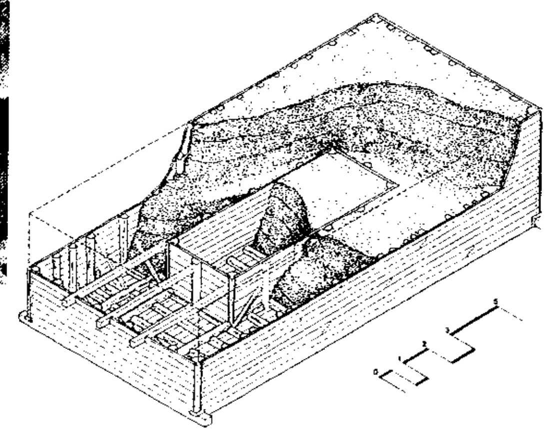


Fig. 3