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STRUCTURAL AND CONSERVATION SOLUTIONS FOR THE TREATMENT OF THE SEA FRONT WALLS OF OLD AKKO (ACRE), ISRAEL

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Abstract. *Between the years 2009-2013, the southern sea wall of the Old city of Akko underwent planned rehabilitation and conservation works funded by the Old Akko Development Company. The southern section of the wall, measuring some 300 m long with an average height of 8 m, was severely damaged by years of marine erosion and flaws in the ancient structural foundation techniques that were comprised of materials unsuited to a marine environment. Moreover, stabilization and rehabilitation attempts carried out in the 1930's of the 20th century also caused irreparable damage to the wall's foundations. The ancient city and its walls are subject to statutory limitations and considerations, as it has been declared an antiquity site by the Israel Antiquities Authority and a world heritage site by UNESCO, and is also a modern bustling town. In addition to these limitations, there are implementation restrictions for construction inside an ancient port, lacking the option to carry out works in an underwater environment. These limitations required creative thinking and structural solutions that would comply with archaeological excavations contemporaneously accompanying the conservations works. Subsequent to preliminary examinations, a temporary rampart was laid out on the seabed parallel to the sea wall without penetrating the bedrock to function as a dam and service road. The intermediate sea area between the wall and rampart was sectioned into pools that were pumped dry to enable dry structural stabilizing, archaeological excavations and conservation works. The accompanying archaeological excavations along the foot of the wall revealed various foundation techniques from the Crusader period as well as the 18th and 19th centuries. Also discovered for the first time were remnants of port structures and facilities dating to the Hellenistic period (3-1 cent. BC), including: stone-built docks and platforms, slipways, rockslides of large buildings and a proliferation of pottery and metal artifacts.*

1 INTRODUCTION

The city of Akko is the only ancient city still thriving within its intact historical walls on the Israeli coast of the Mediterranean Sea. It is a declared "World Cultural Heritage Site" by UNESCO. All construction or development works performed in the Old City are done with conservative guidelines and with the authorization of the Israel Antiquity Authority (IAA). The decision to carry out a massive consolidation project to stabilize large portions of the seawall of Old Akko, was due to continued collapsing of separate stones as well as and large sections of the wall into the sea, as revealed in previous engineering surveys of Akko's sea walls in the 1997 ,2003 and 2008 (ref. [2], [3], [7]). The purpose of this article is to present the challenges, topics and problems regarding the structural consolidation of the southern seawalls of Akko under strict limitations of conservation laws, restricted budget, short time schedule and limited technical resources.

2 ENGINEERING APPROACH TO CONSERVATION AND REINFORCEMENT OF THE SEAWALL WITHIN A DECLARED ANTIQUITY SITE

A Laser Scanning Measuring procedure was implemented and used as a platform for the gathering data in the engineering survey, including information about the seawalls from previous surveys. The Maritime Unit of IAA carried out a survey that included two underwater excavations at the foot of the sea wall.

Based on the Laser Scanning Measurements, Engineering Surveys and preliminary underwater archeological excavations, we were able to conclude the following:

- The foundations of the sea walls were extremely deteriorated and the structural intervention in the years 1940-1970 didn't stabilize their condition.[Fig. 1a. 1b, 1c, 1d].
- The foundations, at least what we know at this stage, were built directly on the seabed or on debris.
- The walls have structural failures that are not only related to the foundations, but also to failures directly connected to the original construction techniques, as well as to building systems of later interventions with Portland cement concrete and due to total lack of maintenance and management plan.
- There were missing stones and large gaps in the lower part of the wall at water level, large cracks and buckling, possible detachments of the exterior stone leaf, with space between it and the interior core, missing mortar between stones and missing pointing,
- There have been all over the wall exposed rusting iron pins between stones.
- On top of the aforementioned, there were damages caused by plant roots creeping between cracks and stones, as well as various inserted elements, such as iron and steel elements or leaking sewer-pipes or gutters or iron..
- There was also possible damage caused by natural sea waves or artificial ones created by motor boats.

Fig. 1a, 1b, 1c.1d   Part of the engineering failures of the sea wall

3 PRELIMINARY ENGINEERING AND CONSERVATION CONSIDERATIONS

The above mentioned information, allowed us to devise a plan for structural and conservation engineering intervention based on the following topics:

- Situation in the area of Crusader Akko's medieval harbor would not enable typical intervention of inserting micro-piles wall into the underwater bedrock following which a dried strip would be created to work on. It would have to be a reversible procedure that would not damage the foundation system.
- Considering that it would be a large and time-consuming project with limited manpower working only in dry areas, the conservation and structural stabilization would have to be performed after drying a strip in front of the wall and working on the bedrock with mechanical equipment and not a procedure of an underwater structural engineering and conservation intervention.
- The intervention would have to be implemented for the full extent of the seawall - from the foundation on the sea bedrock up to the top of the wall.
- The work would be carried out using manpower and equipment of the of the Old Akko Tourism Company who have 20 years of experience in conservation and stabilization works on the inland walls and historic buildings in Old Akko.
- All the materials would be from kurkar (sand-lime stone) and hydraulic lime mortar. It is important to emphasize that the detailed planning of the intervention was in a very delicate antiquity site, with a clear knowledge that intervention in the subsequent sections of the seawall would bring surprises – and they did. Not one section was similar to the other. As the work advanced to the following sections of the wall, we had to change the engineering system of the temporary support of the wall and the system of the engineering and conservation stabilization.

4 ENGINEERING STABILIZATION INTERVENTION DURING THE IMPLEMENTATION PROJECT 2010 -2013

Structural and conservation stabilization of the first 100 m long section (partially on land and partially under the sea) was devised according to the conclusion of the first stage. Based on the successful consequences of its implementation, the next sections were planned and implemented.

A temporary rampart was constructed parallel to the wall at a distance of 6m, to create a dam which would allow drying the land in front of the wall. The rampart served also as a road for the mechanical vehicles and conveying equipment. [Fig.2a,2b,2c]. The rampart was built with an inner pyramidal shaped section piled with a double layer of large synthetic sacks, filled with natural clay sediments. Each layer of bags was separated from the upper one with a double layer of geotechnical cloth. The exterior layer of the rampart was built with large boulders placed on the bank facing the sea to act as a barrier against the sea waves. Crushed kurkar gravel was spread over the upper side of the rampart, creating a large 4 m wide. The cross-section of the rampart was a pyramid with a 30-45* slope; its foot 4 m from the wall, some 2 meters above sea level. In the next strips, the base of the rampart was removed to a distance of 6 m from the base of the wall.

Fig. 2a, 2b, 2c The temporary rampart

The area between the rampart and the seawall was divided into 6 separate "working pools" (areas A-F; Fig.3a, 3b, 3c) and the seawater was pumped out of each 2 pools in turn, enabling contemporaneous archaeological excavation and conservation work. Excavation trenches were dug alternately, with the "stich and un-stich" or "cuci scuci" method, until the completion of the sequence strip along the wall. During the clearing and cleaning process, huge amounts of building debris and garbage was removed to a sorting site; chiseled stones were separated from the field stones and debris, and were returned to the wall to be used in the reconstruction process. The foot of the wall was excavated down to the bedrock and temporary reinforcement scaffolding was erected.

After cleaning a 6 m long section, the wall was reinforced by a temporary vertical, diagonal and horizontal steel post system; after which damaged ancient original lime concrete foundations, the cement Portland concrete beam and sacks filled with 20th century cement, and other rubble were removed. The cement was removed by trained conservation workers, able to implement the work without damaging the stones.

The next stage was the stabilization of the seawall's stones, leaving them in their original position with the help of temporary wedges. After this the construction of the new foundation of the seawall commenced. It was implemented by using a mixture of various diameter cross-sections of rubble stones, with hydraulic lime mortar based on a ready-mix material. The new foundation was covered with a 10-12 cm thick layer of scarifying hydraulic lime mortar.

Grouting was also used as one of the conservation structural methods in the stabilization of the sea wall. The "grouting" work was implemented along the whole seawall.

During the first phase of the grouting process, 1 m bore holes were drilled into the wall, for injecting the grouting material, beginning at the Burj-el-Sultan tower (BST) and continuing westward toward the "Fisher's Harbor". The grouting was injected into the drilling cavities until it spilled outward and was impossible to inject any more material inside. In one of the bore holes, it seemed that the grouting material had spilled into a cavity inside the wall. Examination of vaults 4 and 5 revealed that grouting had really spilled into the vault. As a consequence, the work was ceased at that point. It is worth mentioning that during the operations, it was possible to examine the extent of spilling into the vaults that had openings. It is plausible that there are more vaults along the seawall however their state of conservation is unknown. Maybe some of them have collapsed and filled up with dirt, mud and stones.

Work was done manually without mechanical equipment. The quantity of injection material into each hole was recorded and analyzed at each stage. All in all some 30,000 liters of mortar was applied in an area 300 m (long) x 8m (high) for the length of the seawall. Other applied engineering techniques were similar to the ones used in other historic structures:

- Filling large holes of the interior "core" leaf or the exterior cut stone leaf.
- Closing and "stitching" cracks with mortar injections, stone implementation, replacement and re-pointing.
- Implementing "Dutch work" repairs of large cut stones.
- Conservation treatment of exposed rusting iron pins between stones.

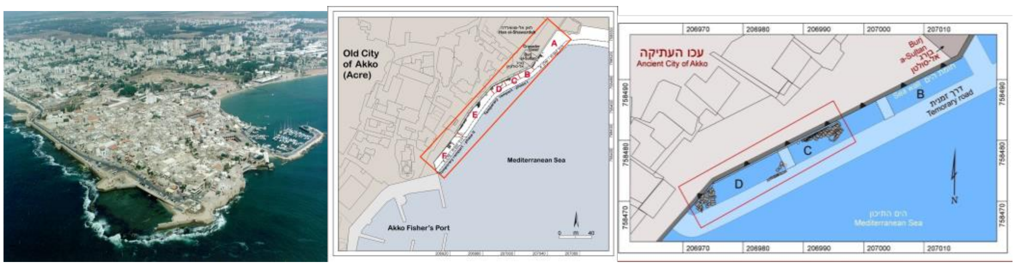

Fig 3a, 3b, 3c Old Akko and the section of the treated section and its "working pools"

5 MORTAR MATERIAL

The basis of the intervention was to use only materials suited to conservation requirements. Lime-based mortar was one of them. An investigation was carried out concerning existing materials for marine environment conservation. The findings revealed that a special Portland cement is usually used in underwater sea structural conservation works, however it was excluded due to conservation restrictions not to use the Portland or similar cements. Other available hydraulic lime products are used only on terrestrial structures without clear long term monitoring or research results. The only company that produces hydraulic lime suitable for undersea works is based in Venice, Napoli and other places, so we therefore decided to use its product, with certain modifications to suit our needs.

6 VISUAL SURVEY

During all stages of structural stabilization, a daily inspection and monitoring survey was carried out by the site-engineer and a weekly inspection was performed by the construction conservation engineer.

7 CONCLUSIONS OF THE ENGINEERING STAGE OF THE PROJECT

7.1 General

The decision whether to intervene came after a long period of visual research and monitoring of the structural condition and deterioration of the seawalls. The real monitoring took place in the last 15 years, and included three engineering surveys performed in 1997, 2003 and 2008 (ref [2],[3],[7]). It also included the study of surveys carried out in 1940, as well as historical documentation from the 13th and 16-19th centuries in maps and written documents. The surveys included also, with limited written documentation, previous local structural stabilization interventions in the 1940s, 1960s and 1980s.

7.2 Previous interventions in the seawalls

It was clear before the intervention and surely after it, that the British Mandate engineering solution using a reinforced Portland cement concrete beam under the seawalls or cement bag supports under the walls, lying on unconsolidated sand, was not a suitable solution for the Akko's Seawalls. The conclusion was that those previous interventions not only were not efficient, but also hastened the deterioration of the base of the wall. More damage was caused by the beam lying on different foundation layers or unconsolidated sand, and because of its rigidity and strong adhesion to the stone it destabilized and brought about the collapse of large sections of the wall.

Even more hazardous than the abovementioned, were changes that occurred in the eastern Mediterranean sea-currents, the construction of the Aswan Dam and the creation of modern marinas that all destabilized the sediments under the seawall foundations.

7.3 Designing new foundations using old techniques

The decision to use the original foundation method based on the ancient concrete hydraulic lime was based on the fact that those foundations in large parts and sections still exist. De facto, sections of the foundations were irregular, in other sections large parts were missing and in some sections they lacked the ancient method all together. Nevertheless, we employed this technique as it is an "elastic" tool, which allows flexibility of treatment in each strip, section or case, as a basic structural solution to the new foundation of the seawall.

7.4 Building the rampart

The parallel rampart built to create a dry space for archeological excavations and engineering conservation works, proved to be a large success by creating a comfortable working area essential for the success of the project. In our case, the habitual solution of using micro-pile walls for the working pools would not have been accepted by the Israel Antiquities Authority. Other underwater engineering and conservation working solutions would not have been feasible to local conservation workers as their training and capacity was limited as was the budget.

7.5 Grouting

Grouting was a major component in the engineering intervention of the structural works. It was performed by a specialized team with 20 years experience. About 30,000 liters of mortar was injected into a total area of some 2000 sq.mr, or an average of 15 liter sq.mr, however, most of the material was injected into 2-3 m above the foundations. Part of the material penetrated into interior cavities of the wall's "core", where we lack information as to its thickness, shape or other characteristics. The seawall has an exterior cut stone leaf with an interior "antique lime-based concrete core" of 3-7 m width, but as were are unable to check its backside, we have to assume that we only partially filled the cavities.

After completion of the works, we carried out a number of horizontal control drillings that revealed that there was a good adhesion between the old and new material and that the grouting filled the cavities of almost all the checked volume. Lacking a professional laboratory for examining the grouting samples limits the quantitative checking of the results of the intervention.

7.6 The "elasticity" of structural planning in restricted antiquity sites

Although the structural and conservation solutions based on surveys and other monitoring procedures and site excavations, have to be planned in advance, there is a large percentage of "unknowns and surprises" working in an antiquity site. There is need for a large amount of local solutions for each case and condition. This means that the engineering must be adapted daily to problems that may arise and produce new solutions for them.

7.7 Materials applied in the project

The hydraulic lime materials used for the works were tested only in the company's laboratory and no examination was implemented on site for testing engineering characteristics.
The limitation created from the fact that there is only one company that uses hydraulic lime for stabilization of historic buildings in seawater, almost ruled out the use of Portland cement that has never been used in marine environments. The stones used for filling in the missing parts were excavated on site stones (ancient collapsed rubble) and are at least 1000 years old, partly deteriorated in the dirty and polluted area, but as the seawalls were built from similar stones in the same condition, the decision was correct; their future deterioration will be contemporaneous with the original seawall stones.

7.8 Professional manpower and equipment

The manpower working at the site was professional with long term experience in structural conservation of buildings and walls in the Old city of Akko. Most of the stabilization and support equipment came along with the team. The only equipment missing was the drilling equipment for "cores" and the laboratory specialized in lime-based materials.

Having trained teams for the works on antique seawalls, could be a critical consideration for the implementation and techniques used for such works.

7.9 Unapplied structural engineering solutions

The original engineering design included a system of reinforcing that was part of the original budget. It included stone fiberglass anchors, "syntax" anchor ties for the entire seawall façade and local stone anchors. After conclusion of work in the first stage, it was decided that the implementation, limited to average sea conditions did not need that expensive solution.

It was suggested by Tourist Offices and Akko Municipality that at the end of the works that the temporary rampart would be transformed into a long term rampart to be used for "defense at extremes" against waves and as a new touristic promenade facing the southern seawall. This proposal was rejected by the Ministry of Environment and the Israel Antiquities Authority as a non-conservative approach, and at the end the entire rampart was dismantled completely down to the bedrock.

8 ARCHEOLOGICAL LAYERS AND STRUCTURES UNDER THE SEA WALL FOUNDATION

Archaeological excavations performed during the conservation works revealed surprise discoveries (Sharvit, et. Al 2013) that necessitated changes to the dimensions of the new foundations however we still applied the planned pyramidal foundation, as follows:

8.1 Area A - Strip of wall between the shoreline and the Burj el-Sultan tower (BST):

Ancient wall foundations made of large finely cut stones built directly on the bedrock (beach rock) were revealed. The base layer of the Ottoman seawall was built on these ancient wall foundations. The excavation also yielded decorated capitals, fragments of columns and scanty remains of Byzantine-Crusader pottery, which could be remnants of the Clarissian Sister's Convent that was destroyed in 1281 when the Muslims conquered the city, as documented by Mondril in 1697 (Schiler 1983) (Fig 7,8).

8.2 Area A - Southwestern corner of the Crusader BST

Excavation revealed that its foundations are also built on the bedrock at a depth of 2.5 m below sea level, with terrestrial-type chiseled kurkar stone blocks(Fig 9).

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8.3 Area B - Strip approaching the BST from the southwest

The Ottoman period pyramid-form foundation built upon the bedrock lying at 2.5 m below sea level. The foundation was constructed of a mixture of field stones bonded together with a kind of cement made of lime and animal bones. Two layers of granite, marble and kurkar Roman columns of secondary use were placed horizontally over the foundation and on them the first stone layer of the seawall was constructed(Fig. 9).

8.4 Area C

Nearby the southern edge of the Ottoman pyramid-form foundation an impressive floor was exposed built of stone slabs each measuring 0.8x0.4x0.15 m. The length of the exposed floor area is some 30m and it continues both northwest underneath the wall and southeast under the temporary dam. The stone slabs were placed on a layer of cut kurkar stones arranged in the header technique. A test pit was dug under the floor revealing a sealed layer of sludge that characterizes the bottom of a harbor; containing numerous Hellenistic finds (3th-1st cent. BCE), attesting to the fact that the platform was built during the Hellenistic period and probably functioned as a docking platform. While constructing the wall during the Ottoman period, a line of columns was placed on part of the Hellenistic floor as the foundation for the wall. This shows that the Ottomans were aware of the Hellenistic floor and used it as a foundation for the wall (Fig.4, 4a, 10). The existence of the quay was also known during the British Mandate as is apparent from a Mandate map based on Marino Sanudo's 14th cent CE map (Makhouly and Johns 1946, [7]:).

Fig. 4, 4a, Foundation of type C.

8.5 Area E

A rectangular structure was discovered (oriented east-west); its entire east section was fully exposed under the wall, as well as sections of the northern and southern walls of the structure that continues underneath the wall. The structure was built directly on the bedrock and includes the remains of a building with 5 layers of cut kurkar rock blocks, about 8 m long and some 1.6 m high (Sharvit, *et.al* 2013: 6) (Fig. 12).

8.6 Large collapsed building

In the gap between the rectangular structure (area E) and the Hellenistic docking platform (area C), a 30 m long rockslide of chiseled building blocks (0.6x0.6x1.2 m) was uncovered, with some intact building blocks. Under the rockslide there was a sealed layer of port sludge lying on the bedrock containing Hellenistic finds. It seems that the blocks belonged to a large collapsed building (Fig 11)..

8.7 Area F – Structures with wooden posts

1) A rectangular structure with a row of wooden posts inserted into its top; the posts continue to the west and east of the structure for a total of some 100 m long.
2) A row of wooden posts some 3 m high with diameters of 20-30 cm; most of them are inserted each 30 cm and in some points, right next to each other (Sharvit, *et. al*, 2013) The bottom tip of each post was sharpened to a point and fitted with a metal spike, some 50 cm long. The spike was made of a 20 cm long cast tip and three wings. The metal spike was intended to facilitate the insertion of the post into the ground levels and the wings were intended to prevent removal of the posts. A horizontal wooden frame was fixed with iron nails to the upper sections of the wooden posts. The first stone layer of wall, consisting of large hewn stone blocks with chiseled frames, was placed over the timber frame. The stone blocks had been dismantled from the Crusader fortress at Atlit and shipped by sea to Akko (Winter 1944b; Makhouly and Johns 1946). The posts are made of a species of trees that grow in the north-east of the Mediterranean (Turkey, Cyprus) – the Pinus Brutia, were dated to the years 1816-1846. This finding shows that this section of the wall was constructed after the city was conquered by Ibrahim Pacha of Egypt, ousting Abdalla Pacha in 1831. It's known that he employed the engineer Declaretto from Italy (Dichter 2000), who brought the post & frame foundation system that was used in Venice (Goy 2006) for enlarging needed areas and rebuilding sea walls(Fig 5, .13).

Fig. 5 Foundation type F

8.8 Area G - Slipway

A rectangular structure 5 m long and 8 m wide with an east-west orientation that continues underneath the Ottoman building, as well as seaward continuation underneath the temporary battery. The structure is built of two thick walls made of large cut kurkar stone slabs that were laid in the header technique (Phoenician style) and in between them is a stone paved floor some 6 m wide with a slight seaward slope.(Fig 6,14)

In the center of the floor there is a 40 cm wide and 20 cm deep groove. In some of the nearby paving stones there are perforations (ca.10 cm diameter) that may have served to hold vertical timbers for supporting ships. At the end of the floor close to the rampart (facing the sea), there are a number of collapsed large building blocks that belonged to the wall. In the nearby excavation trench a number of large detached mooring stones were found. They may have served as part of the dock or for tying ships. Finds discovered in the foundations of the structure are dated only to the Hellenistic period. The structure's location, it size and building technique all point to an installation intended for hauling ships (slipway) or for storing vessels for dry docking, probably a ship-shed (Nauskenea). It seems that the central groove was made to accommodate a ship's keel and protect it during hauling; while wooden poles propped up the vessel during treatment. Similar installations have been studied in many sites around the area of Mediterranean, such as: Piraeus, Bauindinai, Korfu –Greece, Sarkuzi-Sicily and others (Baika 2003; Blackman 2003; Raban 2011) (Fig.6, 14)..

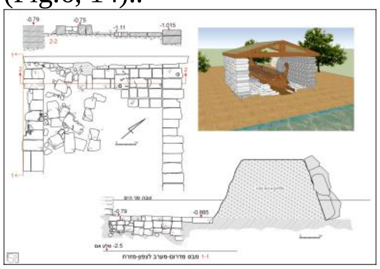

Fig. 6 Foundation type G

8.9 Area H. Area E

The Ottoman seawall exterior stone leaf lies on debris but the inner core layers on an ancient layer may be crusader seawall (Fig. 15)..

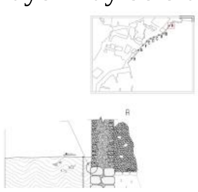
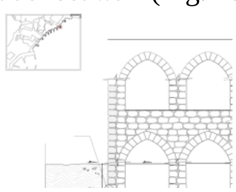
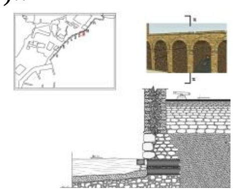
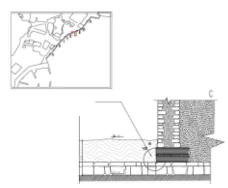

Fig. 7 sect. A   Fig.8 sect. A'   Fig.9 sect.B   Fig.10 sect. C

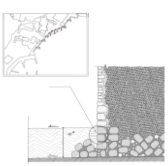
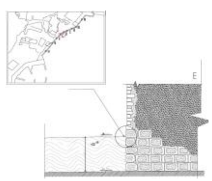
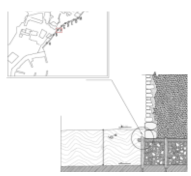
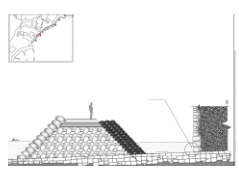
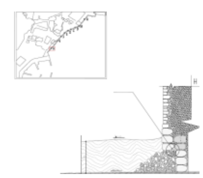

Fig.11 sect.D   Fig. 12 sect. E   Fig.13 sect. F   Fig.14 sect. G   Fig.15 sect. H

9 HORIZONTAL CORE-DRILLING IN THE SEAWALLS

The works in April 2010 began with a site-preparation stage by carrying out a number of core-drillings in the strip of the southern seawall beginning at "Hof Hasusim" beach and ending at the western-most edge of area E (end of phase II of the excavations). The objectives of the core drillings were to study the construction methods, techniques and to examine how deep the grouting filling would reach inside the wall. The locations of the drillings were determined in areas were cracks and geometrical problems were identified by the conservation survey. They were also located so that they would not damage the wall, applying a conservative approach.

9.1 Work method

The horizontal drillings were carried out using a diamond drill, 6 meter long and 50 mm in diameter. During the operations the drill was cooled by a water jet. Core samples were taken from the drill and placed inside pre-prepared long wooden boxes. After extraction from the boxes, the cores were analyzed and the different sediments and fillings were measured.[Fig.16]. It is worth mentioning that areas described as cavities could also indicate spacing between the stones, space inside a vault, or unconsolidated sediment washed by the cooling water of the drill.

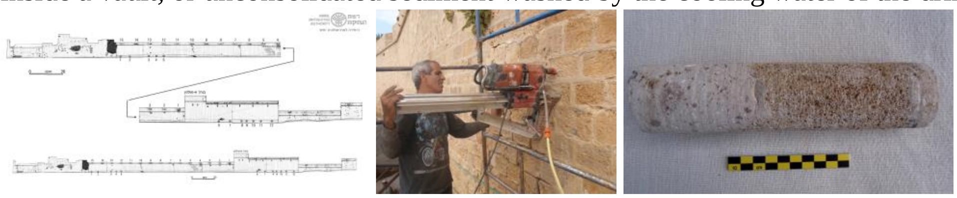

Fig. 16 a, 16b, 16c Drilling of "cores" in the sea walls

Drillings no. 3, 4, 7 penetrated into the cavity of a structure, probably a vault. It is not yet clear whether the vault is whole or rubble of a collapsed vault. It seems as if the drillings penetrated through the foundation courses of the wall that were built with chiseled kurkar-stone 1 m thick and filled with field stones and aggregate.

Drillings no. 5 and 6 were undertaken at a height of 7 m above sea level, from two sides of a crack that was seen in the wall underneath the "balistraria". The drilling revealed that the width of the outer stone layer is 1 m and behind it there is a muddy filling aggregate. Analyses of the array of vaults revealed that the drillings penetrated into a wall supporting a roofed vault built for the canon’s platform.

Drilling no.8 was undertaken at the southern seawall of the Burj-el-Sultan tower. The drilling revealed that the wall was constructed of chiseled kurkar stone 1m wide and behind it 2 m' of aggregate filling containing small stones. Behind the aggregate filling is a cavity and small stones. Examination inside the Burj-el-Sultan tower two story vaulted rooms revealed that the lower vault was used as a water reservoir.

In conclusion, archaeological examinations carried out along the wall in previous years and during the current conservation project, revealed that the wall is built of an array of long and narrow vaults (c. 2.60 m wide, 3.50 m high, and c. 7-8 m long;). In between the vaults there is a 1-1.50 m width of the wall. The external face of the wall facing the vault is 1 m wide. The foundations of the wall stand 1.60 m above sea level and are built of three courses of chiseled kurkar stones, as can be seen through the tunnel of the water canal. Similar core drillings were implemented in 2011 and 2013.

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