

The tanks of the Regia Marina of Monte Erice (Trapani, Italy) on a project by the engineer Pier Luigi Nervi

Roberto Grammatico^{1,*}, Roberto Mazzeo¹

Abstract

The city of Trapani during the Second World War was, due to its geographical position, an important outpost for supplies to the troops engaged on the African front, as well as a submarine base and warships and equally important for the two military airports of Milo and Chinisia and for the hangars of Marsala and Pantelleria. The strategic importance of Trapani was in the storage of naphtha for torpedo boats to defend the naval traffic of the Regia Marina together with the deposits of Cagliari, Palermo and Syracuse. An important aspect that conditioned the construction of these tanks for the storage of liquid fuels, in the years immediately preceding the Second World War, was the difficulty of finding ferrous materials already heavily used for the construction of armaments as well as the autarkic choice of the regime which prevented any importation, for which an alternative construction system had to be sought that would guarantee the stability of structures with large spans therefore, while in the rest of Europe structures with metal frames and roofs continued to be built, in Italy thanks to the scientific and technological research conducted between 1936 and 1940 by the engineer Pier Luigi Nervi on the potential of reinforced concrete was tested and subsequently patented the construction technique of tanks with containing cavities due to the difference in density of the liquids. The discovery in the area of Monte Erice (TP) of a system of tanks based on the Nervi project and the related underground tunnels that connect them to the liquid transfer systems up to the underground distribution point confirm the strategic importance of this area during the second world war.

Key words: royal navy, fuel tanks, reinforced concrete, interspaces, speleothems.

Geographical location and geological outlines

The study area where the Nervi tanks for liquid fuels are located falls within the locality of “Casa la Porta”

in the territory of the Municipality of Erice, in the sud-ovest sector of the mountain, within an area of 2,38 hectares at an altitude of 75 m a.s.l. (fig. 1).

The outcropping lithotype (fig. 2a) in the easternmost portions of the site consists of stratifications

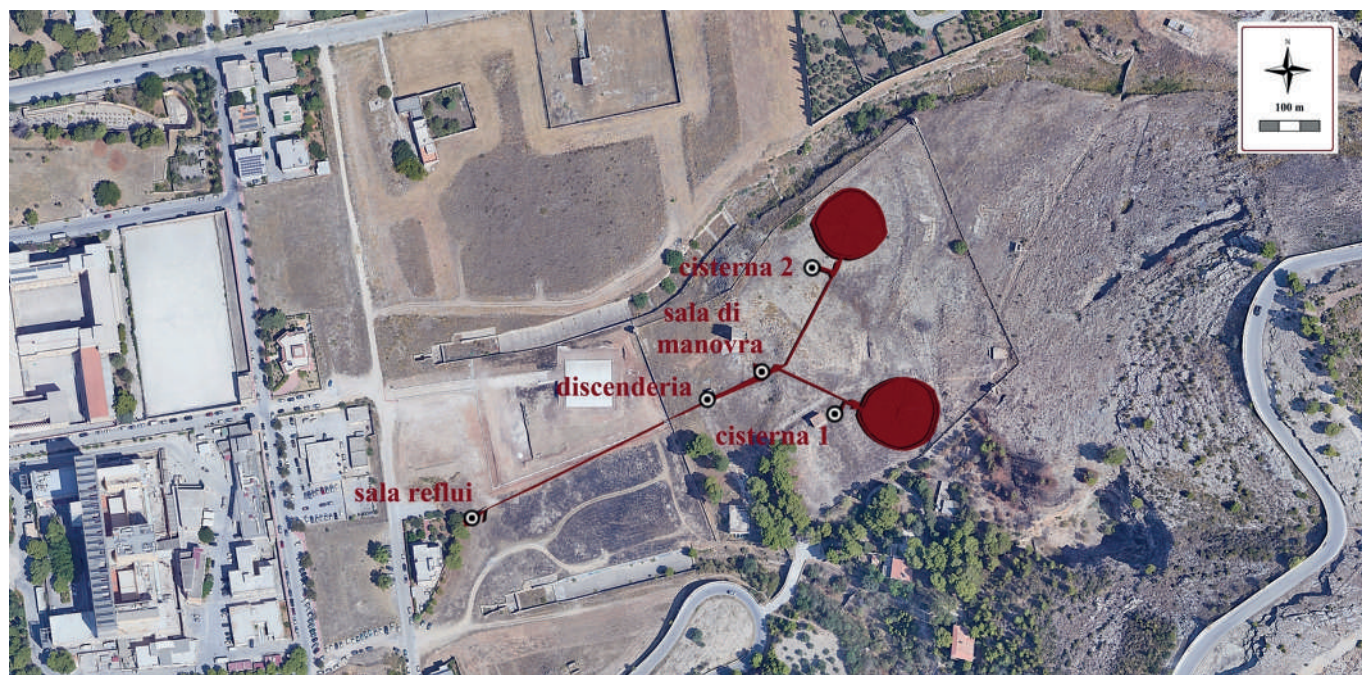


Fig. 1 – Geographical location of Erice tanks (graphics R. Grammatico).

¹ Speleo Team Trapani ETS, Via Case di Grazia 22, 91019 Valderice, Trapani, Italy

* Reference author: Roberto Grammatico - grammarob@gmail.com

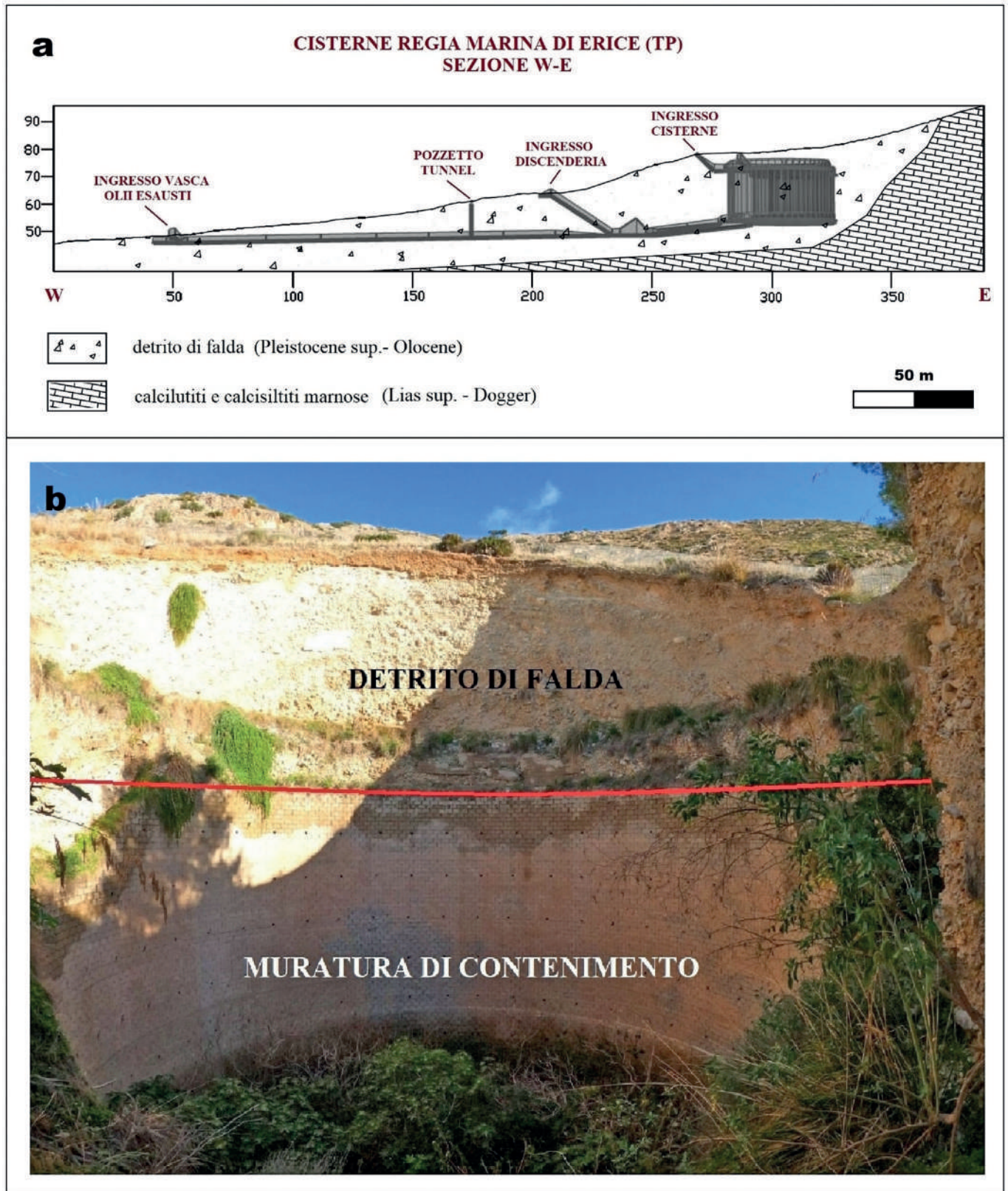


Fig. 2 – a) Geological section W-E; b) Excavation for the construction of the Nervi tanks in contrada Argenteria, north Erice (photo and graphics R. Grammatico).

with decimetre banks of white - gray marly calcilutites and calcisiltites with lists and nodules of flint with paleofaunistic content consisting of Foraminifera, Belemnites, Radiolarians, Brahiopods and fragments of crinoids of the Lias sup.- Dogger

(Wendt, 1971); this lithotype is mainly covered in discordance by a detrital accumulation (fig. 2b) arranged on surfaces of non-deposition and sub-aerial erosion belonging to the Capo Plaia synthem of upper Pleistocene-Holocene and consisting of debris

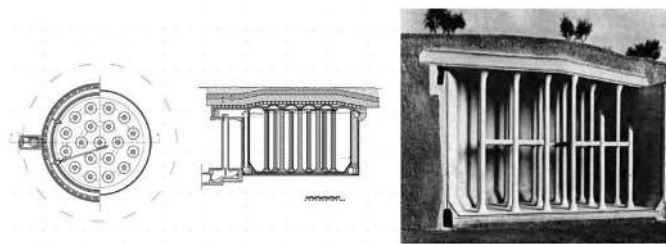


Fig. 3 – Project and plastic of Nervi tanks (adapted from Argiroffi, 2008).

layer of conglomerate size immersed in a matrix of moderately cemented ruditic size whose upper limit is the current topographic surface (Di Maggio *et al.*, 2009) .

Design methods of the Pier Luigi Nervi tanks

In 1935 the engineer Pier Luigi Nervi elaborated, for the Royal Navy, the prototype project for an underground tank in reinforced concrete intended for the storage of fuel called «type Ingg. Nervi and Bartoli». It is a cylindrical structure in reinforced concrete (fig. 3), built using the excavation as a base formwork. On the circular plan, with a diameter of 32 or 36 meters, the columns are set, in number of twelve or twenty-one depending on the size of the cistern, for a height, also variable, of 10 or 16.5 meters. From the prototype project, different solutions were elaborated that responded to the characteristics of the place of construction and to the specific military needs. In addition to the dimensional variants, the typology for “rocky terrain” and that for “no-rocky terrain” are distinguished. Then there is the «simple masking type», which provides only for covering with vegetal soil, and the «armored covering type», designed to resist the direct impact of two 500 kg bombs. The commitment and genius of the engineer Pier Luigi Nervi demonstrated in the search for increasingly performing solutions on the hydrostatic and structural seal of the tanks are highlighted by the succession of patents registered between 1936 and 1940, listed below (Ribera *et al.*, 2014):

- year 1936 - patent n° 338800 - “Tank for liquids lighter than water and not miscible with it, especially naphtha, oils, petrol and the like”. The typology is a reinforced concrete tank with a diaphragm separating water from oil, with tanks having a circular section. This first version of tanks exploits the greater specific weight of the water to reduce the loss of naphtha through probable damage to the shell: a layer of water was interposed, in fact, between the liquid to be conserved and the internal surface of the tank, a layer which, in case of imperfect sealing of the bottom or walls of the tank, it was constantly restored with pumps or other sources in order to avoid any loss of the

lighter liquid stored in them. This typology could also be applied to already built water reservoirs which could have been transformed into tanks for naphtha, oil and petrol;

- year 1937 - patent n°349384 - “Procedure for the construction of a composite cement wall, formed of alternating layers of cement conglomerate and thin layers of pure cement for sealing liquids or gases and the relative product”. It is the first case of a tank with a reinforced concrete shell against the ground. As is known, all conglomerates have a high penetrability to liquids such as oils or naphtha at high pressure. The cement wall in question was formed by a first layer of normal cement conglomerate, onto which, after setting but before hardening, a layer of pure cement mortar and water was projected with the cement gun technique, of a thickness equal to 5 or 10mm. A subsequent layer of normal cement conglomerate was then poured. The layer of pure cement (white and free from blast furnace slag) completed its seasoning in conditions of perfect humidity, being included between the other two layers. The wall thus formed, due to the perfect solidarity between the various layers, was characterized by excellent mechanical characteristics, thanks to the layers of normal cement conglomerate, and by a high impermeability, conferred by the layer of pure cement;
- year 1937 - patent n. 348774 - “Double cement wall for sealing and control for large underground tanks”. The shell in this case consisted of a wall in direct contact with the liquid which was entrusted with the function of sealing and a wall against the ground which was entrusted the function of containing hydrostatic thrusts. Walls and bottom against the ground could be made of reinforced concrete, masonry or be obtained from a regularized rock surface. The innermost wall, in perforated concrete blocks, was to be built at a distance of 10 or 20 cm from the concrete wall, with the holes in the blocks arranged vertically in continuation of each other. As the wall in blocks was raised, a layer of conglomerate was poured between the two walls at a normal dosage and carefully compacted. Grooves were foreseen between a row of blocks and the upper one to accommodate a reinforcement formed by Ø 5 iron rods. These rods were drowned in the concrete casting, protruding from the sealing wall in blocks. A similar stratigraphy was foreseen for the bottom, in which the perforated blocks obviously followed a horizontal structure. All the channels that were formed by the succession of blocks converged in perimeter galleries at seabed level of the tank, entering via steel or asbestos pipes closed with a screw cap. Furthermore, the layer of conglomerate thrown into the cavity was kept in constant humidity, by circulating water in the vertical channels of the perforated blocks. While the concrete was acquiring its mechanical properties, a 20 cm wire mesh was joined to the bars protruding from the blocks, finished with a subsequent

casting of a 7 cm layer of cement paste using the cement gun technique;

- year 1937 - patent n° 355466 - "Improvement in underground tanks for liquid fuels and the like, in order to make them suitable for the attack of aerial bombs". In this case the truncated-cone tank consists of two walls with an aerated cavity; the internal wall which contains the liquid is metal while, the external one, is in reinforced concrete and has a section that gradually decreases as one moves away from the roof, namely as the effects of a deflagration are reduced;
- year 1938 - patent n° 363646 - "Procedure and device for creating and maintaining a layer of pressure determined in value and direction between two bodies, for example between a building structure and the supporting ground". Engineer Nervi experiments with the First method of preventive forcing. In many technical fields it is necessary to solicit two contiguous bodies or one in the presence of the other by means of a pre-established force. The state of stress is activated by means of special devices, which in turn need accessory elements and, once the desired state has been reached, it requires subsequent actions to be kept as such. The 1938 patent applied this principle to the walls of the tank, which, previously stressed, were prepared to resist the pressures of the liquid substances they were to contain, without the risk of uncontrolled deformation. To this end between the walls to be put in a reciprocal state of stress the introduction of bags was foreseen made of flexible and different material depending on the nature of the walls which were then filled with cement mortar or asphaltic substances. Thus, a well-defined pressure was created on the entire surface of the bags which, following the subsequent hardening of the injected substance, would keep the state of compression constant due to deformation;
- year 1938 - "Improvement of concrete tanks for liquid fuels". This patent introduced the typology of tanks with cavity in loose material. The impenetrability of the oils inside the conglomerate is given by the presence of small quantities of water inside the pores of the same; over time, the loss of water in the pores of the concrete makes the material more permeable to petroleum products. The patent solved the problem by keeping the concrete wall always moist, through the introduction of porous and rot-proof loose material (such as pozzolan, pumice, crushed stone, coke powder or diatomaceous earth) inside the cavity formed between two layers of cement conglomerate; the loose material tended, in fact, to retain large quantities of water between the pores, which kept the adjacent internal concrete wall at a constant humidity, making it impenetrable to the hydrocarbons present in the tank;
- year 1938 - patent n° 364418. This patent made some improvements to the seal and was applicable to any tank with reinforced concrete shell. The patent, called "Improvement of tanks in reinforced concrete for liquid fuels", aimed to reduce the drying out of the cement wall that made up the shell, using hygroscopic substances (such as calcium chloride) in the preparation of the plaster applied to the external surface of the tank, capable of absorbing atmospheric humidity;
- year 1938 - patent n° 375055 - "Procedure and device for creating and maintaining a state of pressure determined in value and direction, between two bodies, for example between a building structure and the supporting ground". In this case, the Nervi & Bartoli firm achieved a high level of specialization in the induction of states of compulsion between the structure and the ground, developing what can be defined as the second method of preventive forcing. The inner wall of the tank was made with special lean concrete blocks composed of two parts, one C-shaped and one T-shaped, placed side by side and between which a jute tube was inserted. After installation, the jute pipes were filled with water, thus causing the two parts of the blocks to move away and the formation of cavities (in an alternating position with respect to those containing the pipes) which were, therefore, filled with cement mortar. After the mortar had set, the bags that contained water were emptied by unscrewing the cap present in the inspection tunnels and subsequently extracted from the interspace. The forcing blocks could be placed side by side with a load-bearing masonry structure or with a reinforced concrete mantle against the ground, allowing for the compaction and settlement of the soil-structure system;
- year 1939 - patent n° 377827 - "Improvement in the construction of masonry tanks with sheet metal lining, especially for liquid fuels". Introduction of a system to solve some executive and operational drawbacks for masonry tanks with casing in thin metal sheets. In fact, a method was presented which allowed for checking the welds between the joints of the various sheets before being put into service, as well as checking the seal over time. The system envisaged arranging the metal jacket not in direct contact with the wall structure, constituting the walls and the bottom of the tank, but leaving a cavity of limited thickness between them. The plates were fixed with nails, whose heads would then be covered by welding, on wooden currents fixed in turn with clamps to the wall structure. This made it possible to test the tightness of the welds by introducing lightly pressured air into the cavity, at the same time passing a soapy solution over the surface of the sheet: the formation of bubbles would have highlighted even the slightest leak. Furthermore, by assigning a slope to the wall structure, any loss of liquid that would have occurred during the operation phase would have been immediately detected by inspecting the manhole positioned at the pre-established point of convergence;
- year 1940 - patent n° 384152 - "Improvement of tanks for liquids and particularly for hydrocarbons through the adoption of bottoms or walls in plastic clay". The latest family of underground tanks de-

signed by Nervi belongs to the typology with plastic clay walls, exploiting the principle according to which clay, sufficiently pure and suitably treated and compacted, is perfectly impermeable to the passage of liquids, such as hydrocarbons. The clay was then placed on the bottom and in the cavities of the mantle and was constantly kept in a plastic state, as well as constipated;

- year 1940 - patent n°388212 - "Improvement of tanks for liquids and particularly for hydrocarbons through the adoption of bottoms or walls in plastic clay". It provided for the case in which the underground tank was built in clayey soil, very compact and therefore already impermeable in itself.

Description of the Monte Erice tanks

All the tanks projects were probably carried out by Nervi's own firm, the «Nervi & Bartoli» but the locations of the locations are still covered by military secrecy even though some of them have been made state-free so that the discoveries are always random as in the case of the 12 cisterns of Monte Pellegrino in Palermo whose identification took place due to the collapse of the cover of a cistern and the consequent formation of a chasm. In the case of the cisterns of Monte Erice in Trapani, the discovery took place by young people who entered the shafts and who informed the writers of the presence of cisterns, wells and underground tunnels. The underground structure (fig. 4) has 4 entrances which lead to the various underground rooms. The first 2 entrances communicate via an 11 m long stairway and a short 5 m long tunnel with the two cisterns, accessible via a walled-in iron ladder (fig. 5a), with a diameter of 36 m and a depth of 19 m for a volume equal to 18,270

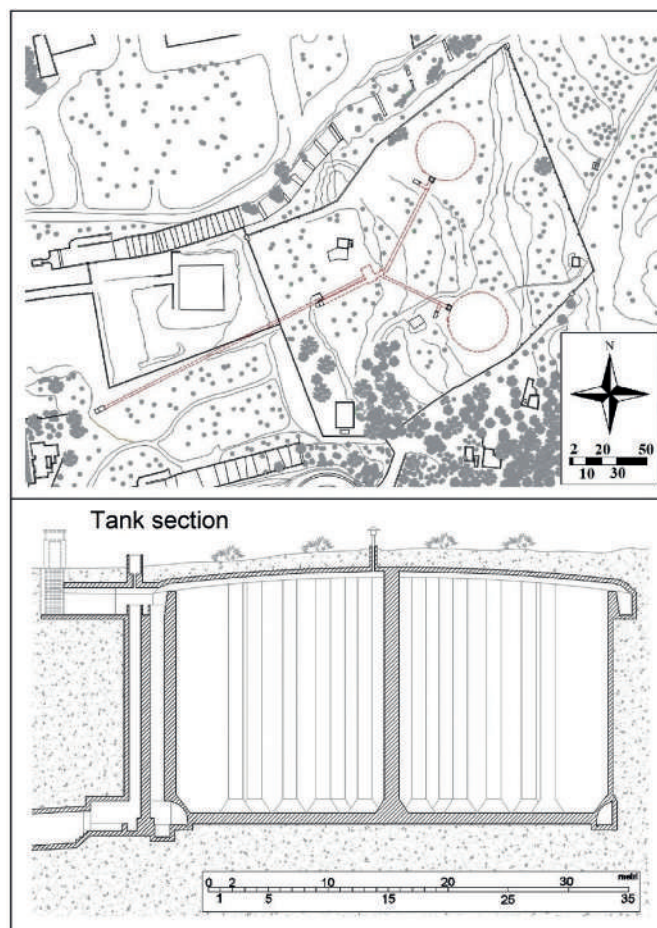


Fig. 4 – Plan and section NNE-SSW of Monte Erice tanks (graphics R. Mazzeo).

m³, 28 load-bearing columns (fig. 5b) arranged in concentric circles with a diameter of 1.2 m with shape at the base flared outwards up to a diameter of 2.8 m

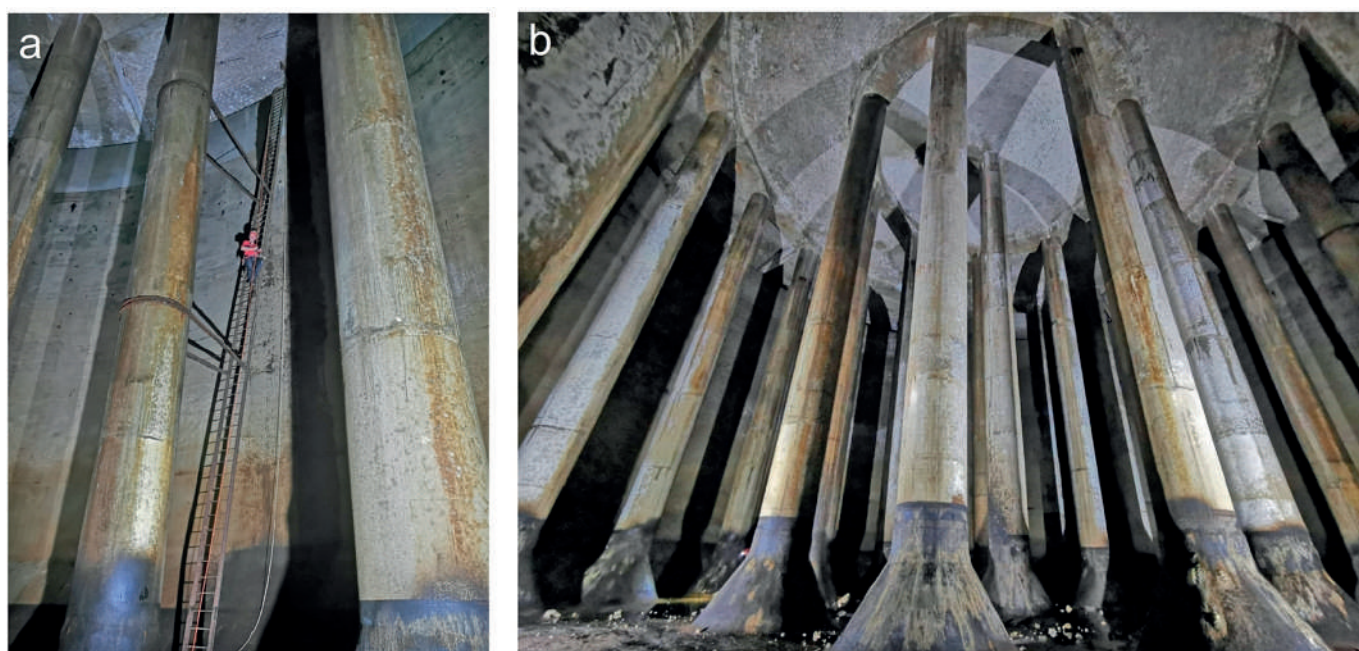


Fig. 5 – a) Access stairway to the Erice tanks (photo D. Clemente); b) System of columns bearing Erice tanks (photo D. Caparotta).



Fig. 6 – Pipes for water injection: a) horizontal injection; b) vertical injection (photo G. Monteleone).

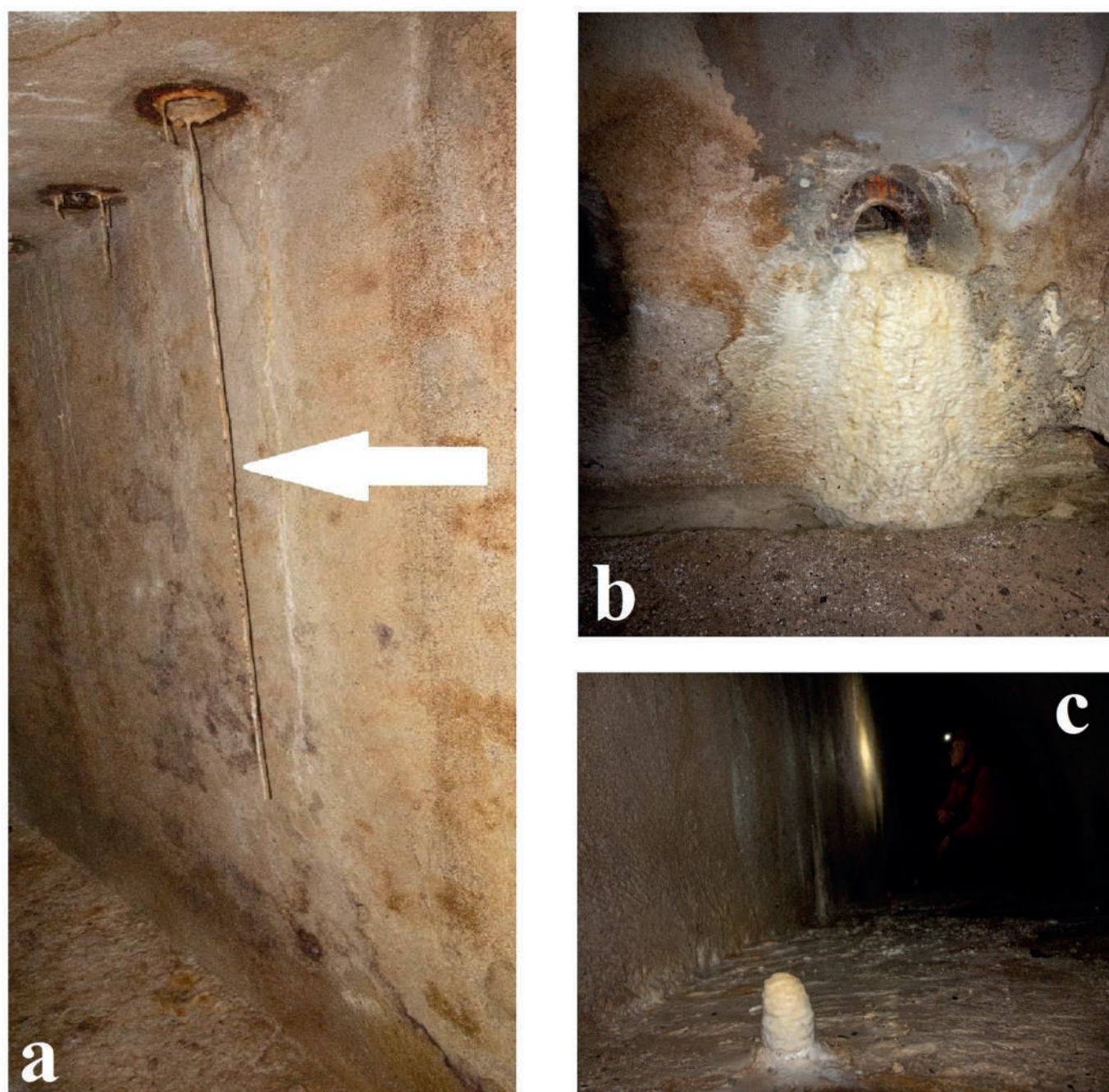


Fig. 7 – Speleothems on water input pipes: a) cannulas; b) crusts; c) stalagmites (photo G. Monteleone).

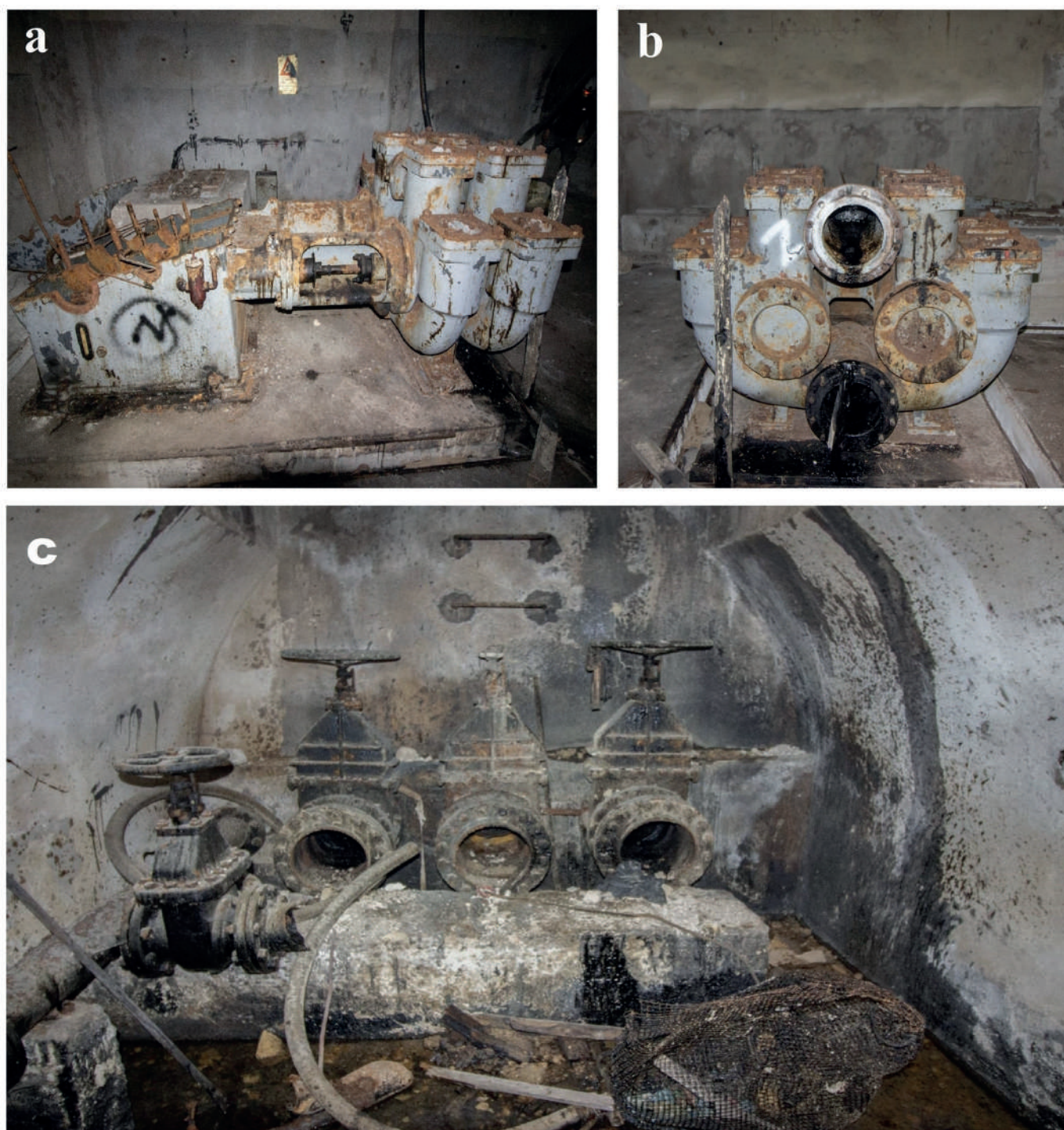


Fig. 8 – Pumping system: a) side view; b) front view; c) maneuvering shutters (photo G. Monteleone).

while the internal perimeter of the tanks has a flared shape towards the center.

The tanks can be traveled up through a tunnel along the entire circumnavigation and through a well with an iron staircase one enters the basal portion of the same, which can also be traveled through a tunnel throughout the circumnavigation. At the base there are the pipes for the transfer of liquids. All the pipe ducts, both horizontal (fig. 6a) at the base of the tanks and vertical (fig. 6b) on the wall of the tanks, which were used to introduce water into the containment interspace, are also visible. Of interest is the

formation of speleothems along these pipes due to the percolation of infiltration water with very thin cannulas over a meter long (fig. 7a) and the formation of stalagmites at the base (fig. 7c) as well as very white calcium carbonate crusts (fig. 7b). Another entrance leads to the main descent 32 m long consisting of a staircase flanked by a slide useful for moving materials inside the tunnels. The shaft communicates with a maneuvering area where there is currently a system for the forced movement of fluids (figs. 8a, 8b) consisting of a pumping system with an internal combustion engine. Two tunnels branch

off from this maneuvering area, one of which in the nord-nord-est direction 44 m long and another in the sud-sud-est direction 20 m long, which lead to 2 rooms connected to the base of the two cisterns where the maneuvering gate valves are located (fig. 8c) and two 18 m high vertical shafts which are connected via a walled-in iron staircase with the upper part of the cisterns. Another 170 m long tunnel branches off from the maneuvering area which, at a distance of 61 m, has a vertical ventilation shaft 13 m high; said tunnel leads, on the bottom, to an environment where there are currently aspirators for forced ventilation and a tank for the collection of

waste currently filled with oily substance; *just before this room there is a staircase that leads to another entrance while before the staircase, on the left wall of the tunnel, there is the connection of the pipe which is buried in a northerly direction towards the discharge points of which an intermediate hut is known at the point with UTM coordinates 33S 284845.99 E 4211810.76 N and probably a final unloading point located on the beach of San Giuliano with UTM coordinates 33S 283559.50 E 4212506.44 N where there is a "shed of 30 square meters for docking of submarine cables" owned by the Ministry of the Defense of maritime state property.*

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