The ancient ports of Rome: new insights from engineers

Alberto Noli (MODIMAR srl, via Montezebio 40, 00195 Rome)

Leopoldo Franco (University of Rome 3, Department of Civil Engineering, v.V.Volterra 62, 00146 Rome)

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Sommario/Abstract

La memoria fornisce, con la prospettiva dell'ingegnere idraulico-marittimo, una rivisitazione della portualità nella Roma antica ed in particolare del grandioso complesso imperiale di Portus e della sua più verosimile configurazione planimetrica. Sorprendentemente ancora oggi la geometria del cosiddetto porto di Claudio non risulta definita con certezza, nonostante la disponibilità di varie pur contrastanti ricostruzioni, in attesa dei risultati di avanzate prospezioni archeologiche.

Viene ripercorsa l'evoluzione storica della portualità ostiense e tiberina sottolineandone l'importanza per l'impero e l'eccezionalità dell'opera d'ingegneria marittima, con significativi contributi alle tecniche moderne. Si discute specificatamente sul classico schema portuale romano "a moli convergenti con isola-antemurale" impiegato anche a Centumcelle ed in altri porti minori mostrandone la funzionalità ed i limiti, anche con simulazioni della penetrazione ondosa con modello matematico. E' sollecitata la cooperazione multidisciplinare degli studiosi e la valorizzazione archeologico-turistica del complesso portuale di Portus.

Foreword

The paper gives an overview of the development of the ports of Rome in the antiquity with an engineering perspective . The importance of navigation and consequently of ports was very large in ancient times and especially in the Imperial Age when commercial maritime traffic was complex and busy, and essential for the supply of food to the population of Rome.

Surprisingly, there is still poor and uncertain information about the large harbour complex of Portus, the most famous Roman port. This review aims to update available knowledge and provide the analysis of hydraulic engineers in order to support the work of archaelogists, who often forget to take advantage of the contribution of researchers from other disciplines, sometimes interested to historical facts and works of the past.

Roman harbours in the Republican Age

The town of Rome is located along the river Tiber at some 35 km “water distance” from the Mediterranean sea. The river is characterized by destructive floods but also relatively high discharges in the summer period, which allowed the transit of vessels with a draft up to 2 m at the mouth. The safety against inundation and of navigation was managed by the “*curatores alvei et riparum Tiberis*”, the old important Water Authority. Navigation along the Tiber could be carried out as far as some 100 km inland.

No news exist about a Roman seaport terminal until the 4th century BC. The port of Ostia, so named for its position at the river mouth (*ostium*) was operational since about 330 BC and the river-bed path was then different from today’s (fig.1): the ample final meander called *fluminis flexus* by Ovidius was cut through by the catastrophic big flood of 1567 AD. The left banks along this meander were used as refuge harbour for *onerariae* ships up to 25 t displacement (net loading capacity of 3000 wheat *moggi*). The goods were then transferred onto the river barges (*naves caudicariae)* which were towed by oxes or slaves from the river banks (preferably the right one) upstream to the *portus tiberinus* in a 2-3 day trip. This river city port was first located on the left arm of the Tiberina island, then relocated on the right bank (today Ripa Grande) and then again on the left side (near Testaccio).

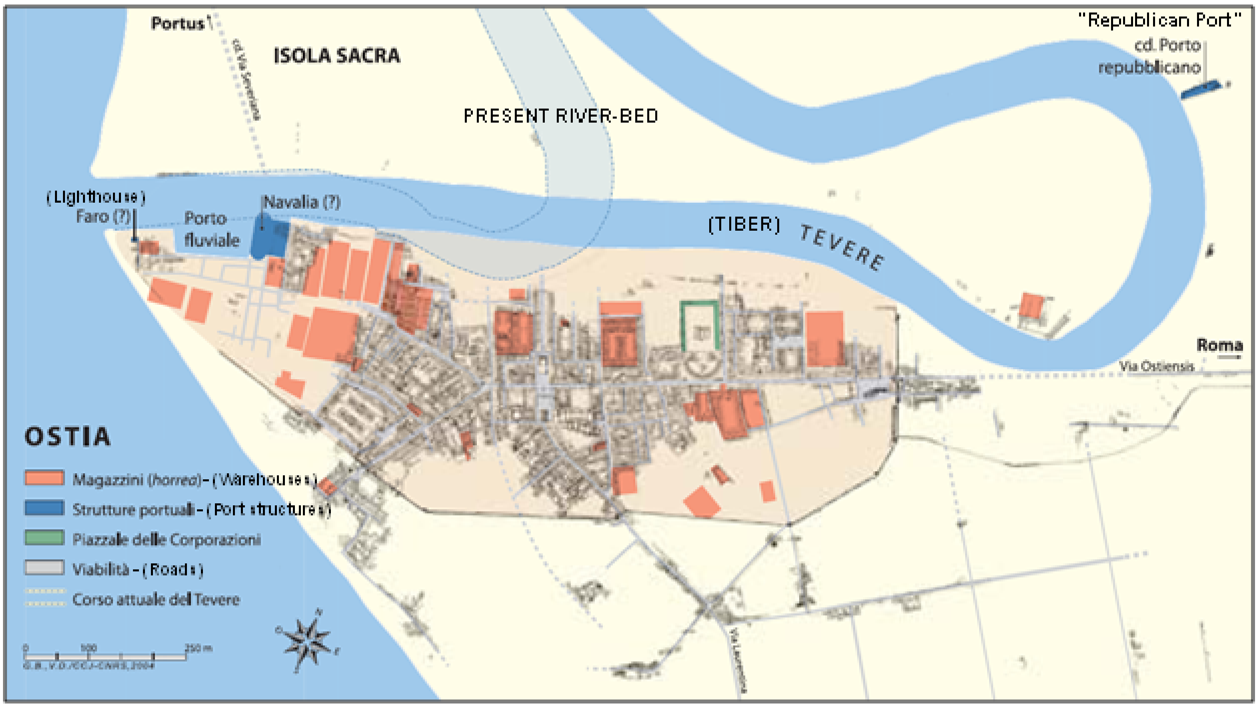

Figura 1 - The plan of the ancient harbour of Ostia (from Lazio’s ancient ports, ANSER project).

The large general cargo ships *(onerariae)* used to make transhipment operations on smaller vessels offshore Ostia to allow the consequent river navigation. Off-loading of goods from ships anchored in the open sea was difficult and dangerous; thus the port system in the 2nd century was extended as far as Pozzuoli *(Puteoli)* where significant transhipment was taking place (up to 300,000 t of wheat from Egypt !).

A location map of main ancient harbours along the Tyrrhenian coast near Rome is shown in fig. 2, together with the offshore wave climate (polar frequency diagram) at Ostia (obtained from transposition of new accurate 15-year instrumental records): it is noted that the prevailing waves come from the WSW sector (*libeccio-ponente*), while a secondary directional sector is S (*scirocco-mezzogiorno).* There are no reasons to believe that the wave climate of 2000 years ago was different from today's.

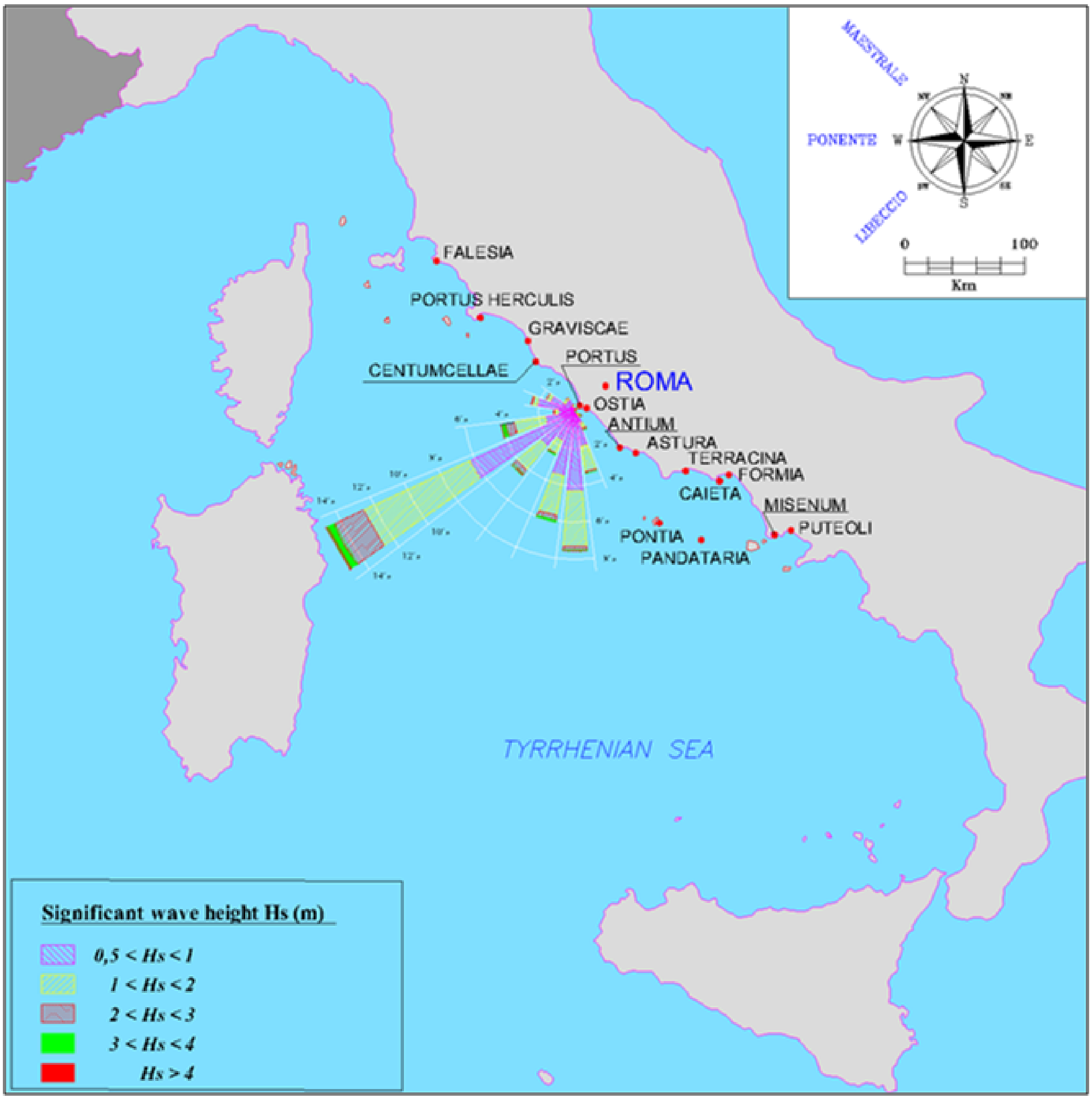

Figura 2 - Geographical map with location of main ancient harbours near Rome and representation of the directional wave climate offshore Ostia after transposition of Ponza buoy records 1989-2005.

The port system of Claudius and Trajan (Portus)

Since the times of Julius Caesar (1st century BC) there was a need to replace the port of Puteoli (as well as the near military harbour of Misenum) with one or more harbours closer to Rome, in order to enhance control and reduce risks of cargo losses along the route. Caesar conceived two important civil engineering works to solve the hydraulic and maritime problems of Rome: first a Tiber flood overflow channel bypassing the town from around Ponte Milvio down to about Ripa Grande, second a large channel between Rome and Terracina with the additional function of a partial safer inland navigation from Puteoli. These projects were long discussed but were abandoned.

Later on the emperor Claudius (ruling Rome in 41-54 AD) constructed a number of important hydraulic works, such as the Claudius aqueduct and the Fucino outlet channel, and also the well known new artificial external seaport on the coast at 3 km north of the Tiber mouth, a position strongly opposed the experts. The new basin was created at a coastal lagoon, which can typically form at river deltas in tideless seas (see for instance the present mouth of the Rhone river in fig. 3).

Figura 3 - Example of river delta in tideless seas with lateral spits and bays to be used for port development (the Rhone mouth from Google Earth)

According to Svetonius, "Claudius built the port by creating two arms (left and right) and a central breakwater at the deepwater entrance. To provide a solid foundation a ship was sunk which had transported a big obelisk from Egypt and a very high tower was raised similar to the Alexandria lighthouse to guide ship routing with nocturnal fires" (fig.4).

According to historians, this ship of Caligola, the largest of those times, had transported a ballast of some 650 t of lentils. The engineer O.Testaguzza (1970), based on these news and on ship traces found on the "left" mole near Mount Arena, believed that the ship had a length of 100 m, width of 20.3 m and draft of 6.5 m. However these dimensions appear to be overestimated, since even today a wooden ship of such size would create building problems; the actual largest ancient ship, as reported by Luciano, was "only" 55 m long and 13.5 m wide and the Caligula's ship was probably of similar size.

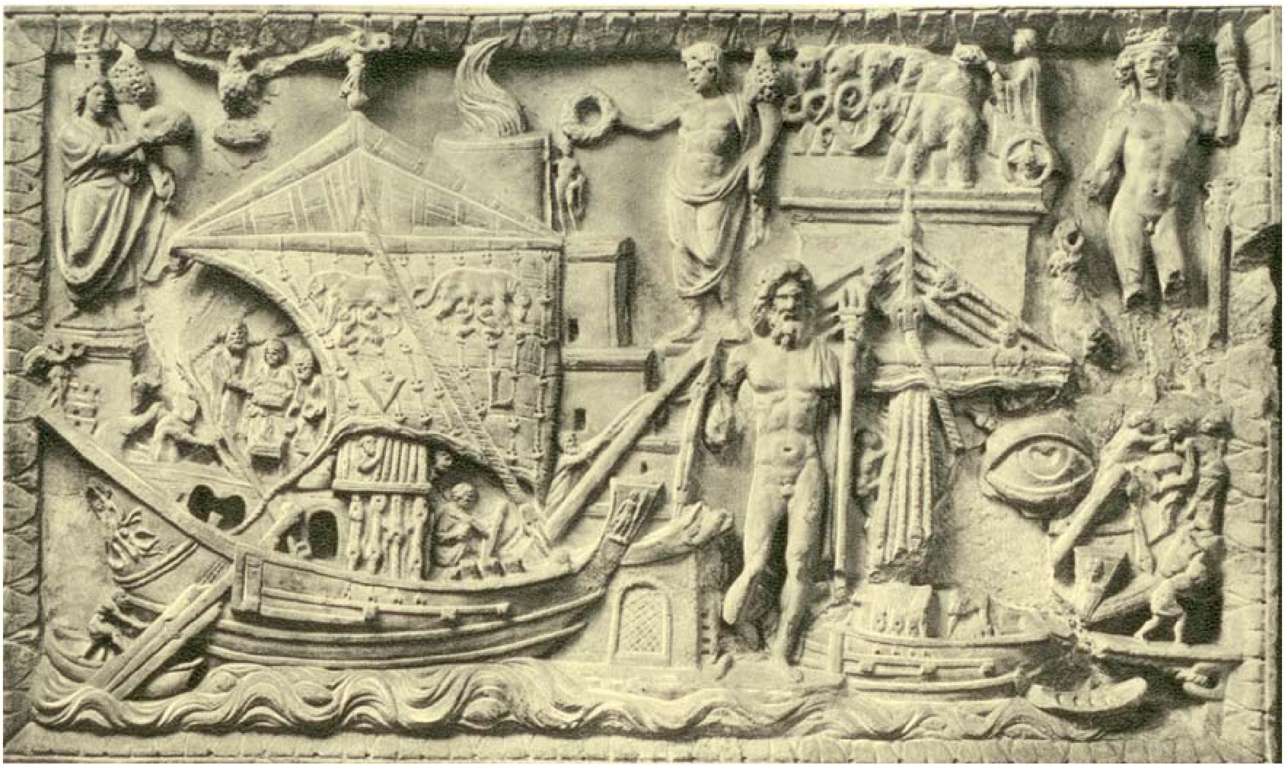

Figura 4 - Marble representation of Claudius port and lighthouse (from Lugli and Filibeck 1935).

The port was mostly obtained by excavation of large volumes of sand. No data are available about the actual port water depths, but it is reasonable to assume a value of -4/-4.5 m MSL to allow berthing of the largest ships of the time. Recently a few authors (Giraudi et al. 2007) have found depths of about 8 m MSL in the harbour basin, but it is likely to be a local feature related to ancient river bed positions, since expensive overdredging would not be justified.

Claudius also built two channels (*fossae*) in order to provide a link between the port and the river and even to reduce inundation levels in Rome. However this latter aim is known to be uneffective for modern hydraulic experts, unless the channel diversion would start upstream of the town of Rome. In fact the Caesar's idea to use the Pontine swamps as flooding areas could have been more effective, even if recent poor experience (eg. Arno, Ombrone) shows that the maintenance of such channels is critical to ensure their efficiency during extreme floods.

The selected location of the new port of Claudius was opposed by the expert engineers who were following Vitruvius' recommendations, due to the siltation problem caused by the sediment supply of the Tiber. Even then the delta was advancing into the sea: a shoreline accretion of about 650 m at Fiumara Grande is estimated to occur between 330 BC (Ostia castrum construction) and 110 AD (new lighthouse at entrance in a position later occupied by the Boacciana Tower). Then the shoreline continued to advance until 1950 for about further 4 km, before erosion processes begun (fig.5) (see also Pio…..2008).

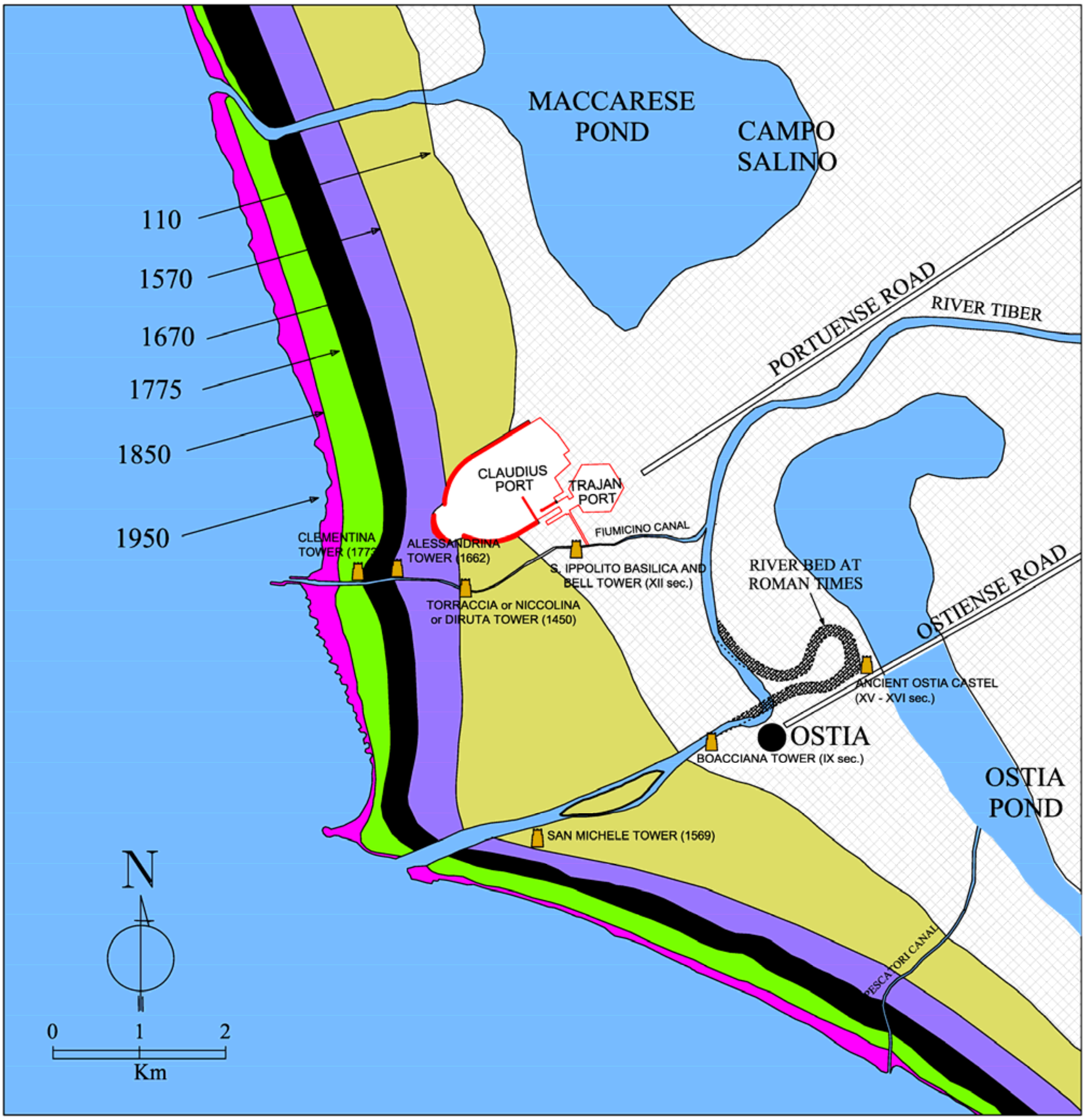

Figura 5 - Historical shoreline variations at the river Tiber mouth (partly from Bersani and Moretti 2008)

The rate of coastal accretion was particularly high in the period between 1570 and 1850 due to increased rainfall, extensive forest cuts and agricultural developments. The local eusthatic sea level rise of 1-2 m in the last 2000 years has only marginally contrasted this process of shore advance.

However, despite the Senate opposition and the very large construction cost (even at present times!), Claudius decided to go ahead. In fact the berthing basin had a surface of more than 150 Ha: assuming that some 100 Ha were excavated on dry land for an average depth of 4 m, it comes out a total dredging volume of 4 million cubic meters of sand.

The importance of this exceptional engineering work was admired by Giovenale and also recorded in an marble inscription (see Lugli and Filibeck, 1935). In particular reports and mosaics highlight the value of the entrance lighthouse which used as a model the famous one of Alexandria in Egypt: it is noticeable that the port of Alexandria, the largest in antiquity, was protecting a surface of some 400 Ha (even if a natural island named *Pharos* provided more favourable geographical conditions) including coastal lagoons and inland channels similar to those at Portus.

The port construction started in 42 AD and ended in 64 AD under emperor Nero.

The Portus port layout question

The exact planshape (layout) of Claudius port is still a matter of debate. Available literary reports (Svetonius, Giovenale, Dione Cassius, Cassiodorus, Plinius the young) and coin representations are rather simplified and not all in agreement. Still today the archaelogists are searching for a final evidence. One of the main doubts is related to the entrance type and position: it could be the traditional double opening with central island breakwater with lighthouse (named *insula* by Plinius), or a single opening to the north (against the moderate wave sector), or two quite distant opposite openings to allow different options under variable winds, given the ancient use of sails as ship propulsive action (see fig.6).

According to Lugli and Filibeck (1935) there were two artificial breakwaters following the existing hills of Monte Giulio (right) and Monte Arena (left) (see fig.6A) and the left one was bending to the south to overlap a smaller southern arm fixing a secondary southern entrance: such layout seems not realistic and no archaeological evidence is yet found.

A more recent reconstruction by Testaguzza (1970), based on finding during the construction of Fiumicino airport, is shown in fig. 6B with the main west breakwater partly formed by a natural sand spit, a main north entrance and a possible secondary one through one of Claudius' *fossae.*

A recent reconstruction by Giuliani (1992), as reported in the ANSER project, shows a quite different port planshape: a large basin is enclosed by two converging arms and a central offshore island breakwater supporting the lighthouse in a position shifted to the South-East as compared to the previous schemes (fig. 6C): such configuration proposed by Giuliani would also justify the need of the additional internal straight mole (oriented about N-S) to shelter the later Trajan basin from wave penetration.

Finally fig. 6D shows the port complex represented by S.Peruzzi who visited the still visible remains of the ancient lighthouse between 1550 and 1573.

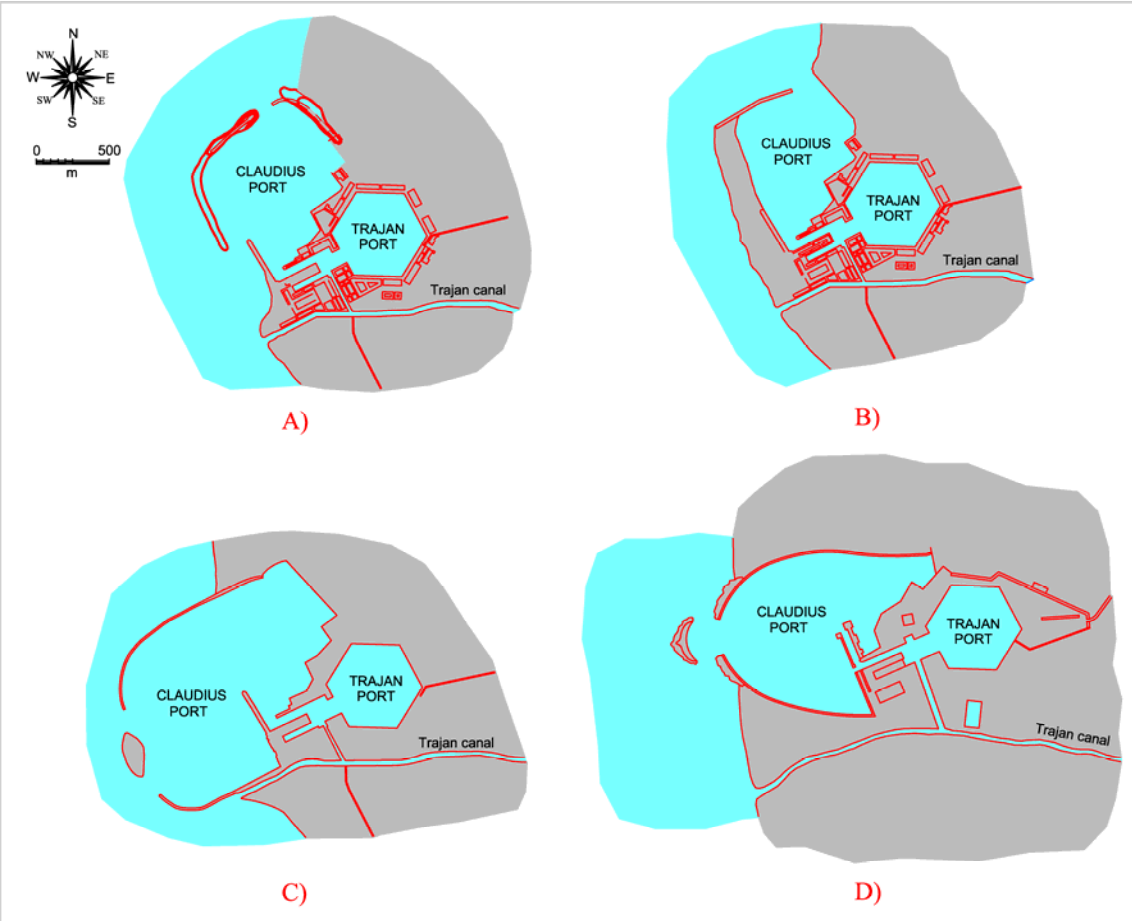

Figura 6 - Reconstruction of the ports of Claudius and Trajan according to:
A) **Lugli and Filibeck 1935, B) Testaguzza 1970, C) Giuliani 1992, D) Peruzzi 1550-1573.**

Claudius basin is given a longer and narrower planshape with the port entrance located further seaward and the arc-shaped central island placed offshore of the entrance gap between the two converging breakwaters and not aligned to their roundheads.

Fig. 7 shows the comparison between the original drawings (produced in the same period) by S.Peruzzi and by A.Labacco (1567) which are in the Uffizi museum. They both provide some distances given in *canne* (one *canna* is about 2 m). The only differences between the two schemes are a more seaward position of the island breakwater according to Labacco and the presence of a double internal mole in Peruzzi’s drawing: the second parallel mole is however not indicated in another prospective view by Peruzzi himself.

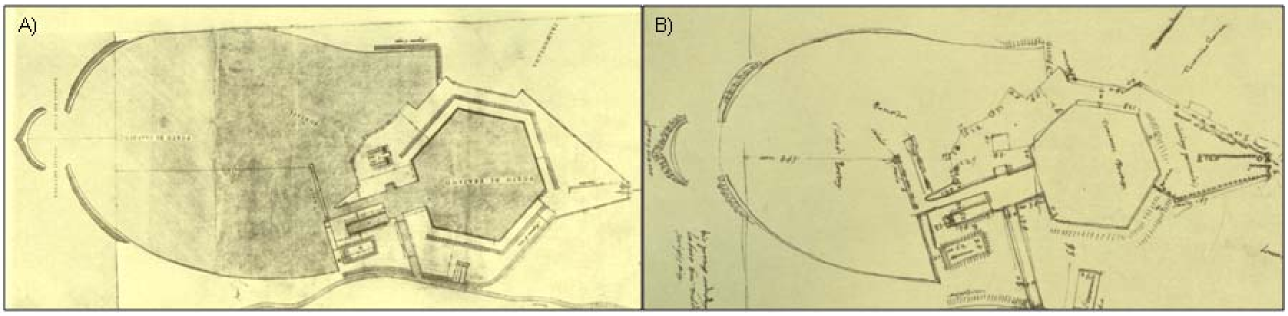

Figura 7 - Original drawings of Portus by A.Labacco 1567 and S.Peruzzi (between 1550 and 1573)

It is quite surprising that, assuming these latter schemes as the most likely ones, no evident traces of such important offshore breakwaters (now inshore) have been yet found by the archaelogists.

Such harbour layout type with double central entrance is quite likely also because of many similar examples in that same period. For example, Fig. 8 shows the layouts of Centumcellae, Antium, Astura and Terracina: only at Terracina the shorter island breakwater (not facing the main wave sector) is located in the middle of the entrance gap and not seaward of it, possibly due to some reference to Alexandria’s port layout by the designer.

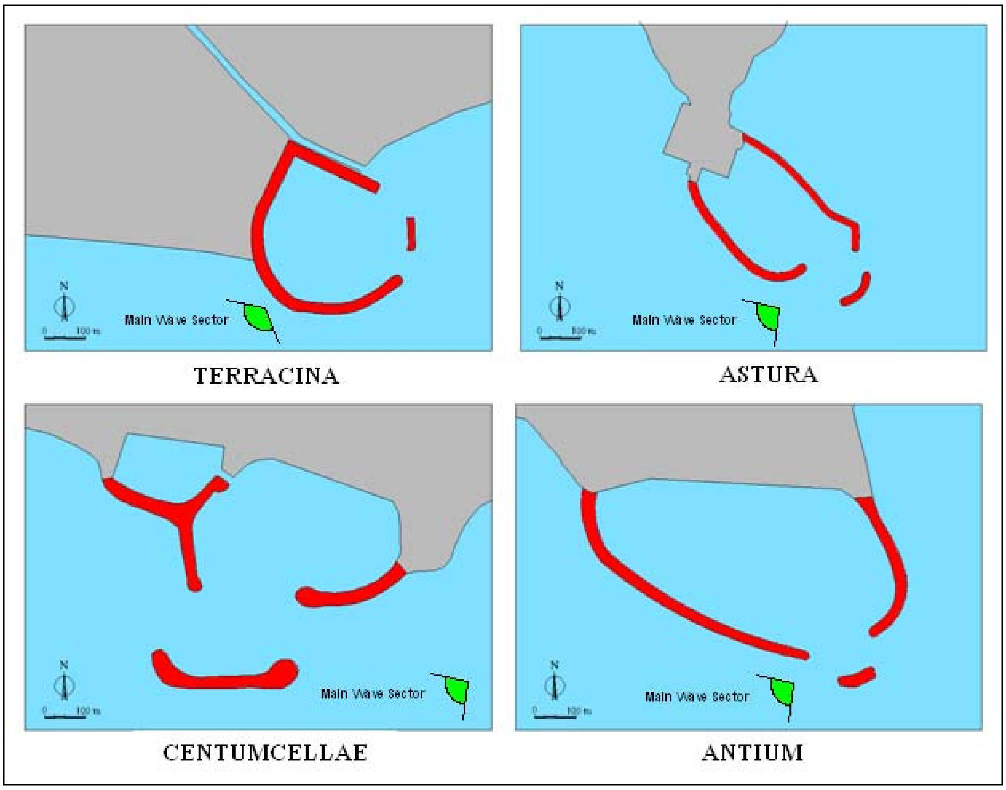

Figura 8 - Roman harbour layouts with double breakwaters and central island.

From the port engineering point of view the offshore island position, as proposed by Peruzzi, is more reasonable than the aligned one assumed by Giuliani, since it provides a better reduction of wave penetration, even if ship entrance manoeuvres may become more difficult (still relatively straight ship routes were allowed).

A recent satellite photograph of the old large eastern port of Alexandria (fig.9) clearly shows how significant wave penetration can occur with the parallel double gap scheme (note that the main wave sector at Alexandria is NW, as also shown by the boats position).

Figura 9 - Satellite view of Alexandria eastern (old) harbour (from Google Earth)

However, even with the longer seaward island breakwater the wave penetration is not negligible, as it will be demonstrated in the following. In fact this could explain the sinking of some 200 moored ships during a severe storm in 62 AD as reported by Tacito. Some authors (Caputo and Faita, 2000) attribute the event to a tsunami generated by an earthquake which damaged Pompei well before the famous Vesuvius eruption (79 AD), but there is no documental evidence of it.

In fact both the large Roman ports of Portus and Centumcelle include a wide "outer harbour" *(avamporto)* and a protected internal mooring basin: the first part seems to be given more attention by the Roman engineers. In both cases however the outer harbour is not fully protected against wave penetration, as demonstrated by some simulations carried out with an advanced numerical model able to represent the combined effects of wave diffraction and reflection (fig.10-11).

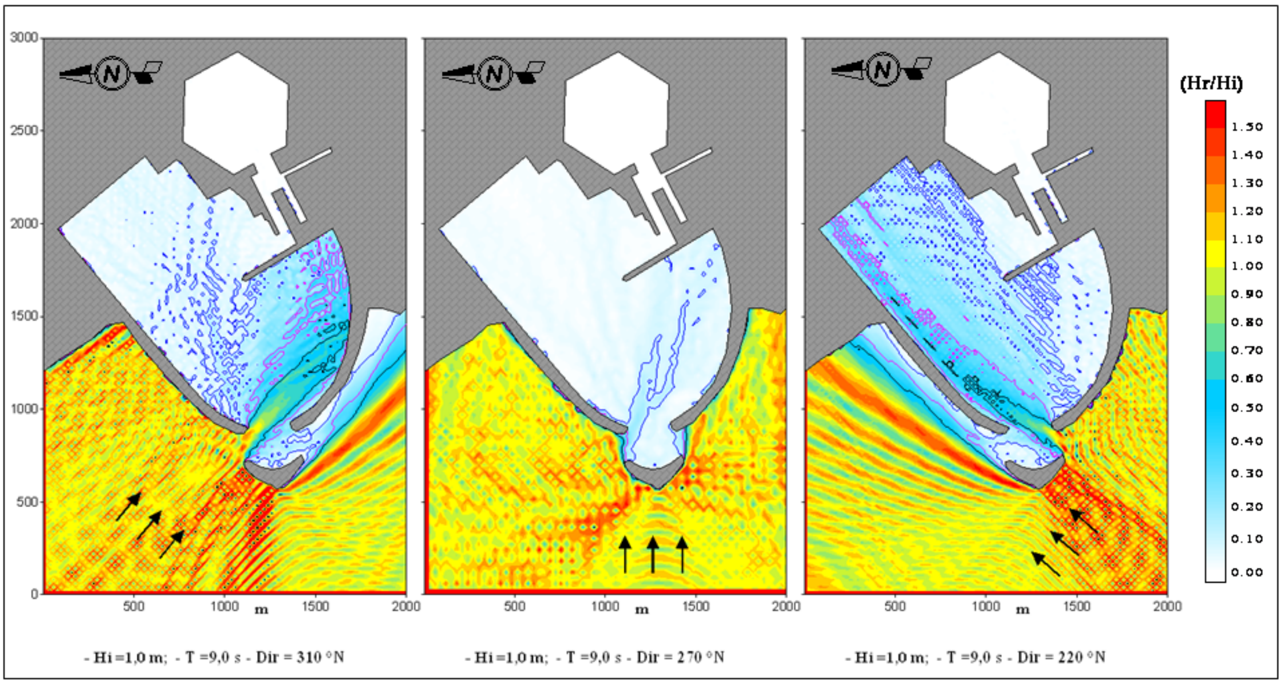

Figura 10 - Wave penetration at Portus (according to new proposed port layout) with mathematical model VEGA

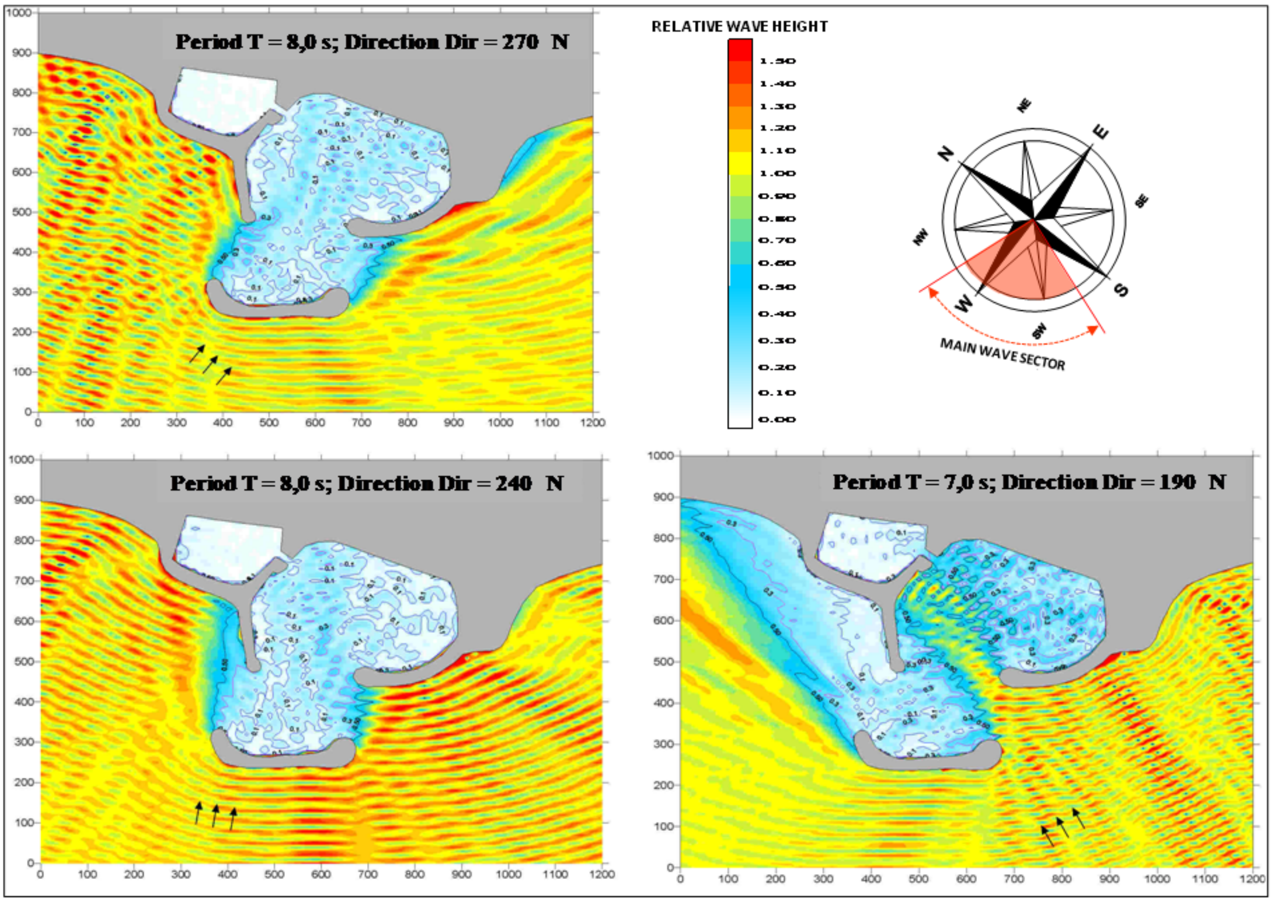

Figura 11 - Wave penetration at Centumcellae Port with mathematical model VEGA

The chromatic plots show the wave height distribution in adimensional terms (ie. assuming a waveheight of 1 m outside the port) for three typical main wave directions and a wave period of 7-8 s. The best port agitation conditions seem to occur under the most frequent perpendicular wave attack from the West-Southwest. It is noted that in both ports very calm conditions only occur in the internal basins (Trajan basin at Portus and *darsena romana* at Centumcellae)

Indeed Claudius conceived the port as one whole basin; the introduction of an internal mole to provide a better shelter to part of the basin is not sure at the early stage , but only after Trajan's architects who also used it at Centumcelle.

It is believed that the ship would be waiting in the outer harbour for their turn at the sheltered quays, moving inside in case of storms. Loading and unloading of goods could take place also during "stand-by" but at slower rates by means of small barges called lenunculi. The high number of ships at peak times justifies the large dimensions of the port. Even today the outer harbour basin has a crucial importance, even if ship stand-by can take place outside the port itself. The main difference is due to the vessel propulsion system: the use of engines now excludes the use of a double entrance which was useful when sailing; a long straight access route is instead preferred today, due to the ship size and limited manoeuvrability. Access speed need to relatively high, especially in hard weather, requiring a stopping distance of 3-5 times the ship length and thus a large outer harbour.

It is hoped that new modern archaeological investigations will finally clear this interesting argument. Indeed Marinucci (2008) gave the news of the finding of the exact location of the island at a conference organized in march by the British Academy in Rome (not yet published at the time of writing this paper) . The actual port entrance position seems to be in good agreement with the one given by Peruzzi, thus justifying the words of Giovenale: "the arms extended long into the sea leave Italy far away".

Thus it gains more value and reality the most famous representation of the two ports *(utriusque portus ostiae delineation)*, often considered as fantastic, due to the Dutch painter J.Blaeu, inspired by a prospective view by S.du Perac (fig.12).

As a matter of fact the drawing by Peruzzi was based on a true topographical field survey.

An additional confirmation of the likelihood of Peruzzi and Labacco's reconstructions is given by the nice painting of Portus ruins by A.Danti (1582) exhibited at the Geographical Maps Gallery of the Vatican Musuem: it shows the position, still in the open sea, of the remains of the final portions of the two converging breakwaters and central island (fig. 13). As useful reference landmark, the painting shows the location of the tower of Pius V, built by pope Nicolò V in 1450 near the shoreline at that time and thus named Niccolina.

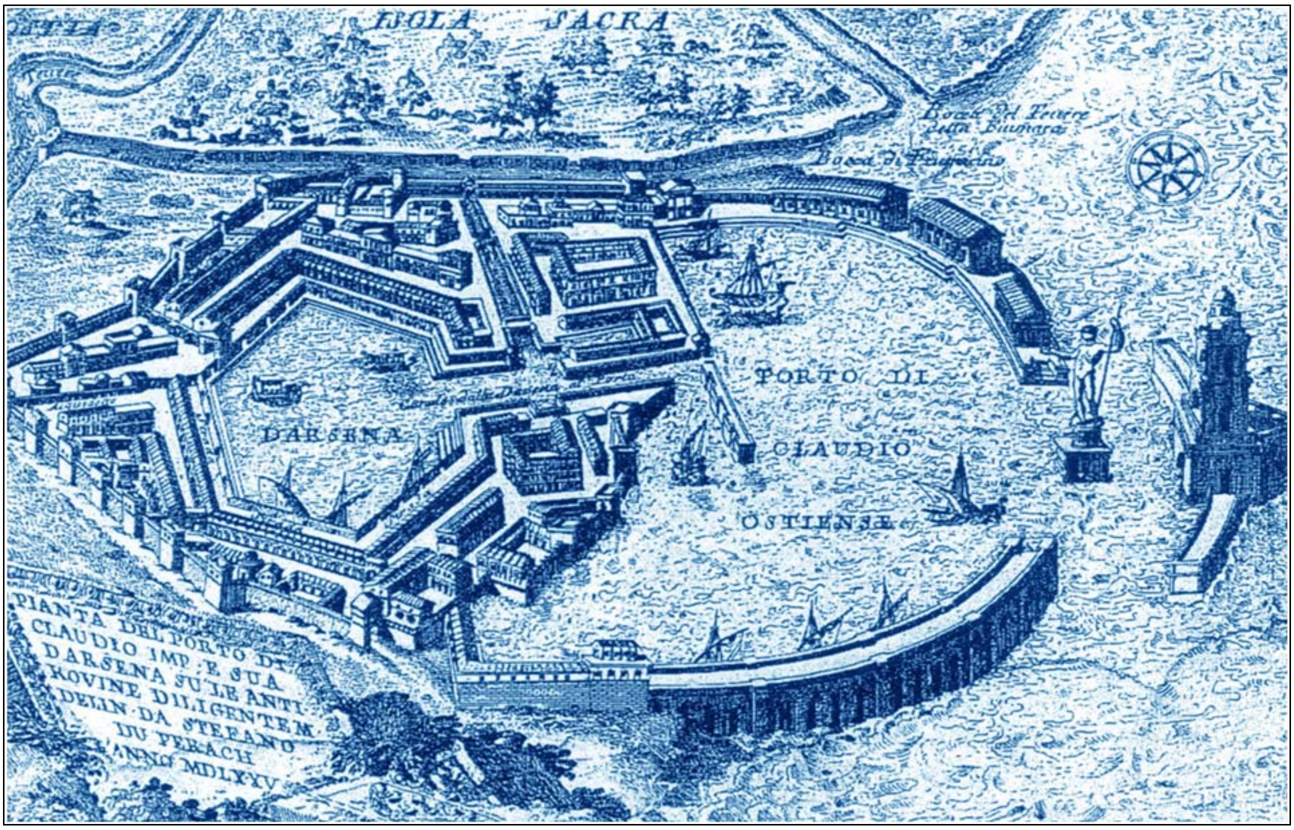

Figura 12 - The most famous representation of Portus (J.Blaeu, 1575)

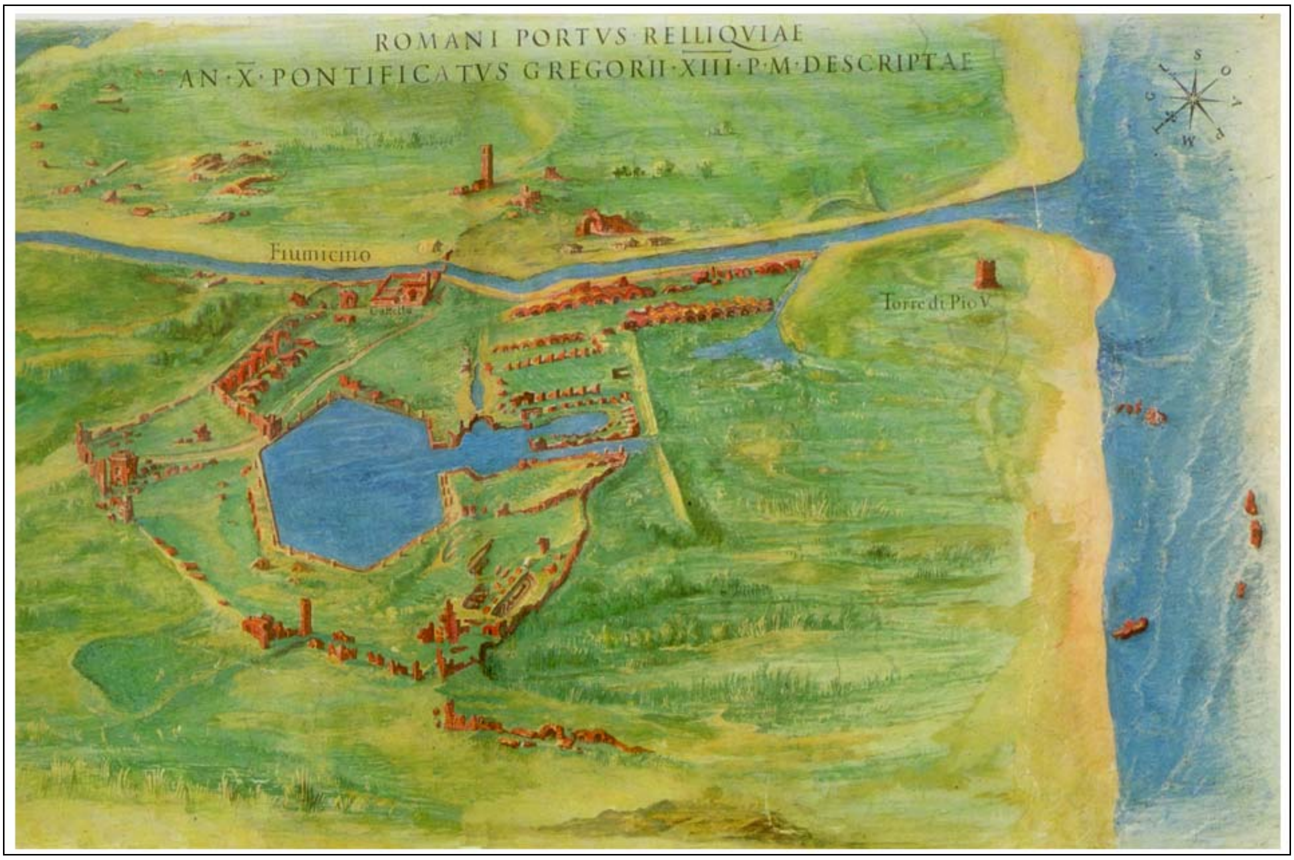

Figura 13 - Painting with the ruins of Portus in 1582 (A.Danti)

While waiting for the publication of the new archaeological findings, we attempt an updated reconstruction of the port based on the available information (fig. 14).

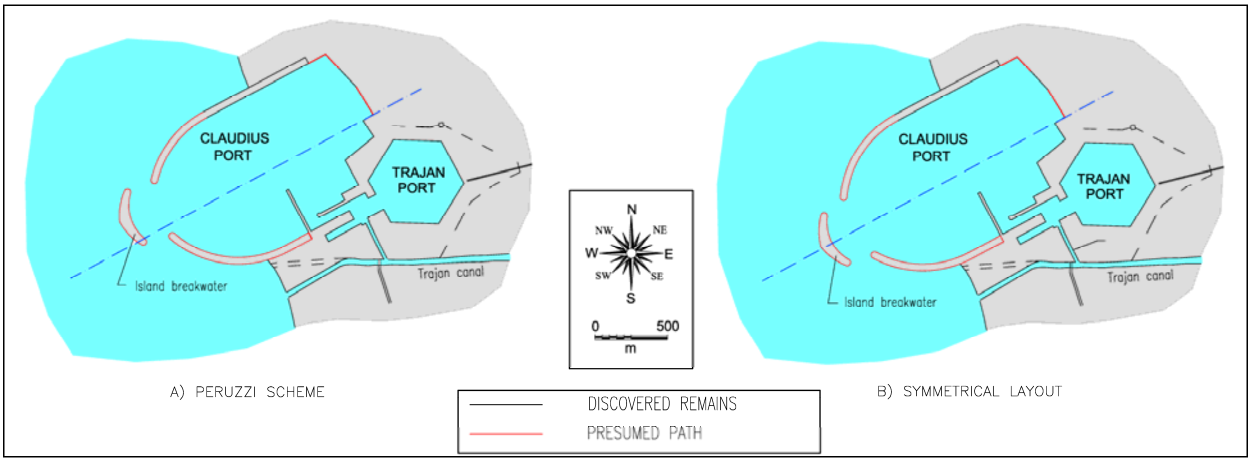

Figura 14 - Reconstruction of Portus according to Peruzzi (A) and proposed by the authors (B)

The two proposed schemes only slightly differ for the position of the island breakwater, which in the first case follows Peruzzi's survey and in the second one (14B) assumes a more complete symmetry of the two converging moles with regard to the entrance axis which is exactly oriented along the main WSW wave direction. Indeed there was no reason to give a non-symmetric shape to the port layout, since symmetry was one of the main architectural features in antiquity.

According to this hypotesis the island breakwater location would have been at a distance of about 800 m from the shore in a water depth of 7-8 m, assuming an average seabed slope of 1% similar to the present slope.

Fig. 15 shows a possible reconstruction of Claudius port only, assuming that the transversal internal mole was already existing (indeed just near the remains of Claudius arcade) to provide a full shelter to a part of the port basin.

It is well known that the port was later extended inland by emperor Trajan between 100 and 112 AD according to Giovenale and Plinius the young. Trajan, who also promoted the construction of the ports of Centumcelle, Ancona and Terracina, excavated a new exagonal basin of 33 Ha (each side is 332 m long), thus transforming Claudius basin in an "outer harbour". The aesthetically appealing geometry of the new port basin makes us believe that the architect was Apollodoro of Damascus, then a favourite of the emperor, who also designed the nice layout of Centumcelle (Civitavecchia) port. This latter port layout became the ideal port model in the Renaissance Age.

Trajan also improved the southern artificial channel by Claudius, by widening it and armouring the banks: this channel is still operational today at Fiumicino.

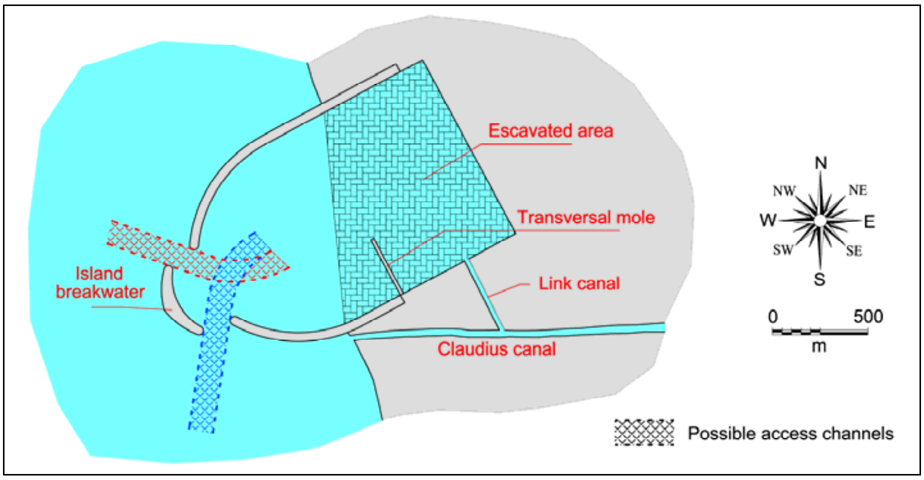

Figura 15 - Schematic reconstruction of the port of Claudius

No doubts exist about the well preserved “port of Trajan”, which was surrounded by a majestic set of port buildings and warehouses *(horrea)* : these ones were useful to preserve the goods with excellent conditions of aeration and safety against fires and robbery.

Portus after Trajan

The following emperors, especially Septimius Severus, continued to maintain and improve the port structures, particularly on land. Under Constantinus the town of Portus obtained the full municipal autonomy *(Civitas Flavia Constantiniana Portuensis)* . Walls were then built to protect Portus from the attacks of pirates and barbarians. In the 4^{th} century the port begun to silt up significantly, despite periodical excavations of the seabed sand (also used as ship ballast).

In 408-410 AD Alaricus occupied Portus, even if new works were later built, such as the Placidian Porticus. A new sack was made in 455 AD by Gensericus, king of Vandals. Even after the fall of the western Empire in 476AD Teodoricus spent some port restoration efforts.

The invasions of Portus and Rome showed the intrinsic weakness of the capital which was too strongly dependent on its port and river for the supply of food. The reduced efficiency of the complex Roman transportation system is infact considered by historians as one of causes of the decline of the empire.

Therefore the selection of Bisantium (Costantinopolis) as new capital of the Eastern Empire was also dictated by the need of a port-city which was more difficult to conquer. Even the western capital was transferred to Ravenna, where the port of Classis was well protected by ponds and swamps.

During the gothic wars (535-553 AD) Portus was alternatively ruled by the emperors Belisarius and Narsetes and by the Gothic kings Vitige and Totila. Afterwards Portus was abandoned and the original harbour entrances were silted up. Thus a new entrance and access channel were probably excavated at the north side at this stage, as represented by Testaguzza (fig.16).

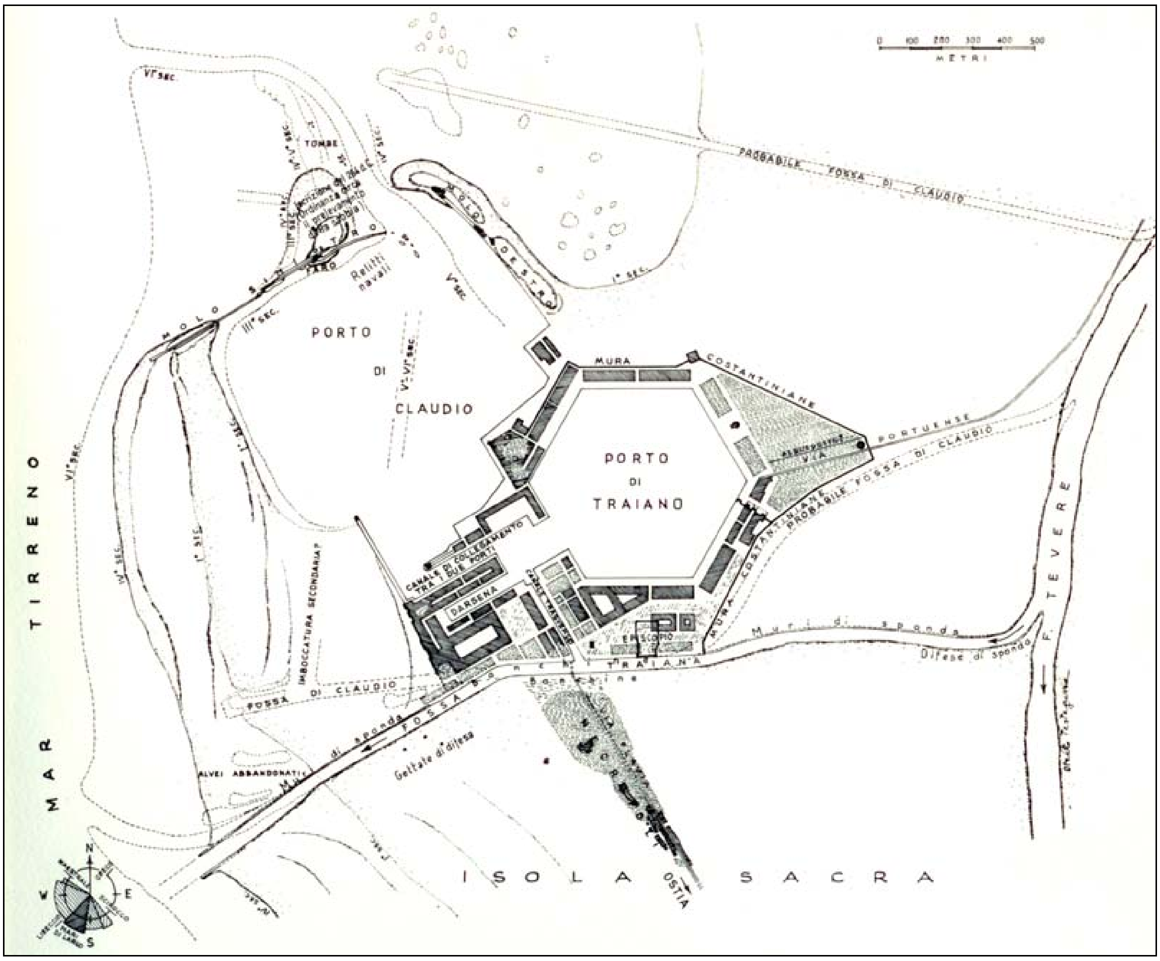

Figura 16 - Reconstruction of Portus in the 4th century (from Testaguzza 1970)

This hypotesis of a successive opening of a northern entrance is also supported by the finding of breakwater armour rocks buried under the seabed of this entrance.

It is important to highlight the validity of the port scheme of Claudius and Trajan, which was operational with continuity for about five centuries, three of them (60 to 337 AD) in good conditions and two more without any maintenance. Thus the port design cannot be considered a failure due to the delicate location near an advancing river mouth. Indeed it showed an exceptional lifetime, also considering that the modern designs of harbours and most civil engineering structures are conceived with a useful lifetime of just 50-100 years. It is felt that the port life could have lasted even longer if the splendour of the Roman empire would have continued with careful maintenance by its managers.

The Roman heritage in harbour engineering

The above considerations can well justify the importance given by archaeologists and scholars to the system of Roman ports, by far the largest and most innovative in antiquity. Reference is also made to Franco (1997).

Unfortunately the Portus site is not easily accessible to tourists, partly because the remains occupy a quite large area, partly because some areas are still undiscovered or covered by new structures, such as Fiumicino airport and its access roads and railway. Today only few people visit Portus necropolis and the Museum of Roman Ships in the airport area, also due to schedule limitations, as well as the remains of Trajan port and its exagonal basin (only after agreement with the Consortium *Oasi di Porto*).

We agree with those who wish to restore the ancient situation, by filling with seawater the Claudius basin and lowering the level of Trajan’s lake, which was raised by the prince Torlonia by means of a dyke with concrete revetment for water storage and irrigation purposes. This idea is anyway expensive with various problems to be solved, such as the underground road link Rome-Fiumicino, the interference with the airport runaway n.1, the oil deposits and the Coccia di Morto road between Fiumicino and Focene (fig.17).

Fig. 17 also describes a possible general future plan of the roman coastal area, which might include four different ports after about 1500 years without any port at all.

We believe that the harbour engineering heritage by he the Romans has a great technical value.

The double breakwater layout with exposed central gap is still today a favourite port design solution for both navigability and siltation aspects. Also the idea of inland excavation is being followed in modern designs (eg. Gioia Tauro, Sibari, Cagliari ports): the Romans used this concept even in rocky foreshores, such as at Centumcelle and Pandataria (Ventotene).

Further modern technical innovations are due to the Romans : for example the use of pozolanic hydraulic cement for underwater structures and the use of caissons or old ship hulls to be sunk in-situ by sand or concrete filling. Remains of caisson “lost forms” are found in the Claudius port breakwaters even away from the offshore island made by sinking the Caligula’s ship.

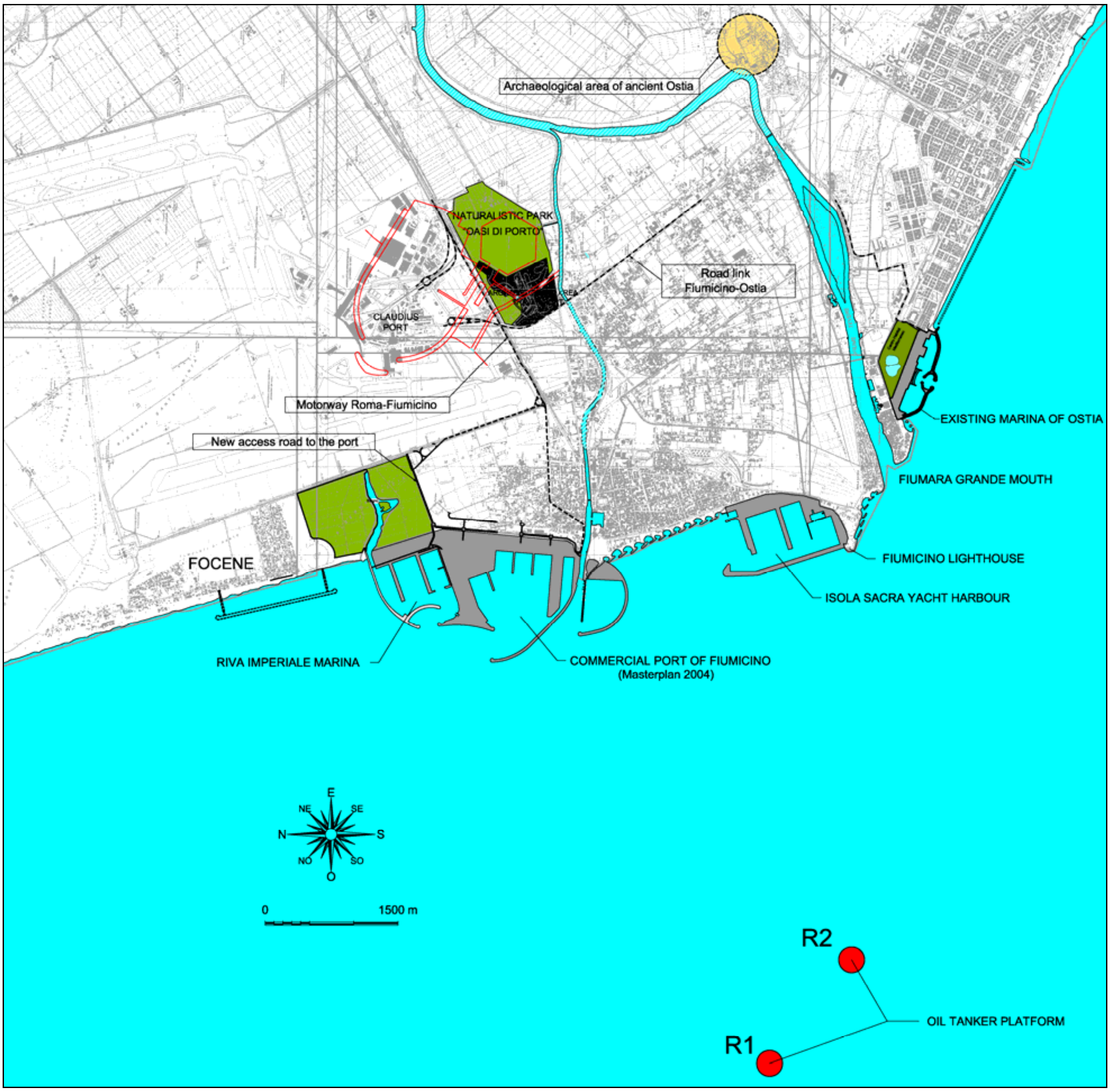

Figura 17 - Possible future port system around the Tiber mouths

Fig. 18 shows the semi-submerged remains of a harbour breakwater made with typical prismatic caissons at the seaside villa of Cammerelle (Sapri).

Also the use of pozolanic concrete is still widespread in modern maritime engineering due to its impermeability and durability, with new specific laboratory investigations being performed on this exceptional construction material.

In addition to the technical heritage further considerations arise from the Roman port engineering experience. When vital needs demanded new large port infrastructures, the Roman emperors decided and completed the work construction within few years, even against the opinion of the experts and of the Senate in the case of Claudius, showing a remarkable courage aimed at the public interest.

Figura 18 - Satellite views and photographs of the semisubmerged remains of a Roman caisson breakwater in the gulf of Sapri

Today, in a much more rapidly changing world, similar important requirements of infrastructural development or protection works (eg. MOSE in Venice, TAV, solid waste plants, etc.) are not followed by rapid construction due to long political discussions and oppositions. The example of the old decision-maker emperors might not be forgotten in order to ensure the necessary development of modern Rome and Italy.

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