Bulletin PIANC
N°97 - January 1998.

L. FRANCO

HISTORY OF COASTAL ENGINEERING IN ITALY

by

Leopoldo FRANCO
Associate Professor of Coastal Engineering
Terza Università degli Studi di Roma
Dipartimento di Scienze dell'Ingegneria Civile
Via C. Segre 60
00146 Roma, Italy
Tel : 39 6 55175024, Fax : 39 6 55175034
E-mail : leofranc@fenice.dsic.uniroma3.it

FOREWORD

Due to stringent space constraints this paper summarizes very shortly the content of the slide lecture presented at the PIC'97 in Venice. A more extensive version (although still necessarily condensed) of this historical review can be found in Franco (1996 b).

INTRODUCTION

The Italian peninsula is like a giant *pier* jutting out in the middle of the Mediterranean Sea. Due to this strategic geographical location with a total coastline extension of 7500 km and an over 3000-year-long history of human civilization (with difficult inland communications, for both geographical and political divisions), it is easy to understand that Coastal Engineering has played here a relevant role since the ancient times.

In particular, Italy and a few near Mediterranean countries retain the unique valuable heritage of ancient harbour engineering, which can still offer a useful background to modern designers and coastal managers. Moreover the conservation, restoration and valorization of these remains in suitable "archaeological coastal parks", or even re-use for modern marinas, could enhance the touristic-cultural offer (Franco, 1996 a).

Attention is here focused on the main technical and scientific contributions given to the global progress of this discipline within a time span of over 2000 years.

As a brief geographical introduction, the location map in Figure 1 shows the subdivision of the Italian seas and coasts (45% are beaches and one third of them are eroding) with the 11 compartments of the central technical authority in charge of the coastal works. The location is also shown of some main towns or ports referred to in the text.

Relevant meteoceanographical conditions are the small tidal range (less than 0.5 m at springs, except for the north Adriatic reaching 1.0 m), the weak currents, moderate winds and the short-crested steep wind-waves (typical 50-year return Hs = 7-8 m). Sea level measurements carried out since 1884 show a mean rise rate of 1.2 mm/year for the period 1897-1942 and 1.54 mm/year in 1931-1971 and 1.6 mm/year today. A global average rise of about 1.5 m in the last 2500 years has been estimated, also based on the present position of the many remnants of ancient coastal works.

ANTIQUE AGE

Harbour engineering originated in the Mediterranean basin together with the development of maritime trade and the

Figure 1 - Geographical subdivision of Italian seas and coasts

technological progress followed the successive dominations of the Egyptians, Minoans, Phoenicians, Carthaginians, Greeks, Etruscans and Romans. For a general review of ancient harbour archaeology reference is made to Blackman (1982) with an extensive bibliography. Within a PIANC environment two monographical historical volumes on ancient Italian harbours were edited by the Marina Militare (1905) and a more technical overview has been recently given by De la Pena et al., 1994. Very few written reports on the ancient methods for design and construction of coastal structures are available. The only technical handbook is the one of Vitruvius (27 BC) mainly related to the Roman engineering experience.

The earliest maritime works in Italy were built in the 1st millennium B.C. along the southern shores by the western Phoenician and Greek colonies. Pre-Roman harbours were «natural», typically located in favourable geographical conditions, such as sheltered bays near capes or peninsulas, often close to easily visible coastal mountains. Their design was mainly dictated by nautical and military constraints, such as providing safe access in hard weather through usually narrow entrances, which could so be well controlled and even closable with chains. Multiple port entrances were often provided, either to ease navigation under variable winds, to separate different port routes and traffic (commercial, military and fishery) and to favour water flow in the relatively tideless basins, in order to avoid harbour siltation. Also underwater flushing channels and tunnels through the moles (eg. Syracuse) were built, often controlled by sluice gates. Even ramps were constructed to allow the wave crests to sweep over the breakwater and collect sand-free water in a tank at a higher elevation for periodical release into the harbour. These port flushing systems are now being again designed with the novel scope to improve water quality in polluted Mediterranean marinas.

In order to reduce large wave overtopping at vertical cliffs and reefs the Phoenicians excavated hollows and trenches in the rock. These «wave catchers» would channel and drain the water off back to the sea and were also used as an immediate source of building stone (Raban, 1988). Sometimes the rock mass was flattened on its landward side to make a naturally sheltered quay. These concepts were applied again by the Romans at the harbour of Ventotene island (while a modern concrete version of this crownwall was recently patented and used at Fontvieille, Monaco). This remarkable well preserved "carved breakwater" is cut from the bed-rock by creating a suitable wave-absorbing profile, with a deep parabolic shape and a mild grooved slope at the waterline (Figure 2).

The western Phoenician colonies later assumed the naval preminence in the Mediterranean Sea under the guide of Carthage (750-146 BC). The characteristic novel feature of Carthaginian (and later also Etruscan) port layouts was the so-called *cothon*, an internal lagoon or artificial basin, excavated behind the coast and joined by one or more channels to the sea. The cothon could be used for the home or the military fleet, or just for ship repair works. Beautiful examples are still visible at Motya (Sicily) and Carthage (Tunisia). At Motya the cothon might have been closable and drainable to be a dry-dock.

An interesting Greek semicircular quaywall with T-shaped blocks was built at Gravisca and it is well visible some 100 km north of Rome. Remains of Etruscan ports (III century BC) also

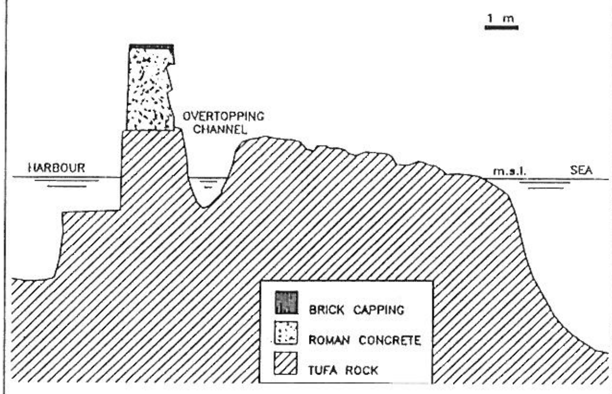

Figure 2 - Cross-section of the existing Roman «carved rock breakwater» with overspill stilling channel at Ventotene (Built 2 BC)

exist north of Rome at Pyrgi and Cosa. Here the nice artificial rock-cut channel (70 m long and 5 m wide, partly tunneled) was equipped with sliding boards to control the desilting water flow between the deep sea and the inner harbour. The Greek and Etruscan breakwaters and seawalls were mostly built with cut rocks regularly placed without mortar on rubble mounds. Also metal joints and clamps were used to fasten neighbouring rock blocks. Typically the pre-Roman ports were part of the town, whereas in the Roman Empire ports will become an independent infrastructure, with own buildings and goods storage deposits.

However, the revolutionary technological innovation introduced by the Romans (II° BC - V°AD) was the discovery of hydraulic cement made with pozzolanic ash from the volcanic region around Naples. Thus they learned to build walls under water and to construct solid breakwaters to protect fully «external» harbours with free planshape, even curvilinear (to enhance de-silting currents) along a coastline without much natural protection. A new tradition of vertical and composite concrete walls (*opus pilarum*) initiated and many of these monolithic structures have survived till today.

However, the Romans properly used a variety of design concepts and construction techniques to suit the local

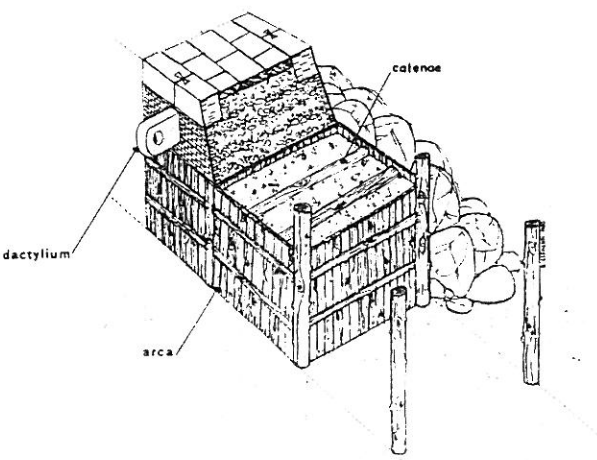

Figure 3 - Reconstruction of the Roman construction system of a vertical breakwater with cast-in-situ concrete within wooden forms and tie-rods (Clementi, 1981)

hydraulic and geomorphological conditions, and availability of materials. On deep seabeds the Romans used to lay a rock foundation up to -6 or -7 m MSL and then construct the vertical wall, sometimes placing a bronze slab for toe protection (Oleson, 1988). In hard bottom soils only a superficial layer was dredged to be replaced by a smooth rock bedding layer. In case of high layers of mud, according to Vitruvius, they used to drive numerous short wooden piles with scorched tip and put coal rock between the pile heads. In fact the Roman engineers developed the mechanical technology of crane hoists and pile drivers, even placed on rafts or barges. In open waters the vertical structure could be built in the dry after pumping out water and leveling the seabed within two 1.5-m-wide cofferdams made with sheetpiles filled up with clay bags. Instead, in sheltered sites they used to pour a mix of cement, pozzolan and brick pieces (impermeable mass concrete) within immersed wooden forms supported by driven piles and tie-rods and later casting a concrete emerged superstructure, about 6 m wide, covered by joined squared rock slabs (Figure 3). Figure 3 also shows the characteristic block with a hole (*dactylium*) used for ship mooring on the rear side: the hole axis could be either horizontal for mooring lines or vertical for a tie-pile, as still visible on the double-level quaywall of Aquileia river port.

Even watertight wooden floating cellular caissons were used to cast the large concrete breakwater at Caesarea. Other original Roman breakwater designs are the perforated vertical wall to reduce wave impacts (Tapsus) and the elegant "arched moles" (Puteoli, Mysenum) which borrowed the technology of bridges and aqueduct (For figures and details, see Franco, 1996 a,b).

Sometimes, instead of the forms, old ship hulls were sunk and filled with concrete, saving time and material. A well known example is the main breakwater of the largest artificial imperial Port of Rome ("Portus") built at Ostia under Claudius around 50 AD, partly by sinking Caligula's 7400 DWT, 104-m-long ship in order to create a solid foundation for the big lighthouse (Testaguzza, 1970). The great breakwater is still partly visible, abandoned within the grass grounds of Fiumicino airport at some 4 km distance from the sea. Chronic siltation problems at Portus later led Trajan to the excavation of a new nice hexagonal basin (360 m side length, Figure 4) and then to create a new harbour at Centumcellae (Civitavecchia) which is still the port of Rome. The basin was here excavated in the bed-rock which was reused for breakwater construction: this rubble mound has been reshaped by man and waves over the centuries to reach an efficient mild-sloping profile (Figure 5).

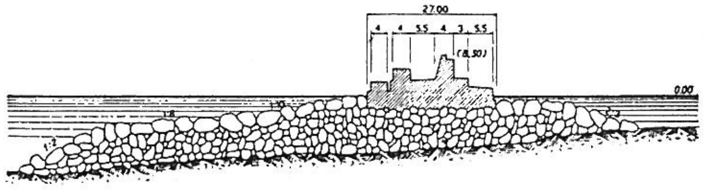

Figure 5 - Modern section of the Trajan island breakwater of Civitavecchia harbour

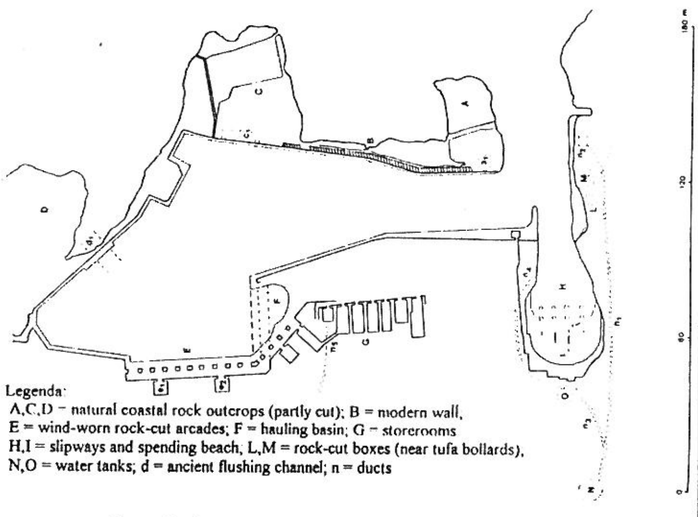

Figure 6 - Layout of the Roman imperial port of Ventotene

Figure 4 - The layout of Portus (Ostia) the great port complex of Rome in a drawing of Du Perac in 1595

The typical Roman harbour layout shows two main converging arms and an island breakwater to reduce wave penetration through the gap, thus providing a double entrance for manouvrable vessels (e.g. Centumcellae, Astura, probably Portus). However, the most modern and efficient harbour planshape (quite similar to that of the newest port of Gioia Tauro!) can be observed in the beautiful and still intact harbour of Ventotene built under Augustus: a bay with spending beach-slipway is located straight after the entrance and a lateral mooring basin is still preferred for its tranquillity to the modern port by the fishing and tourist fleet (Figure 6). Ventotene harbour is really a colossal sculpture, fully excavated into the dark tufa-rock to create artificially a «natural» basin of 7,000 m^2 with 3 m depth, a "carved breakwater", quays, large rock-cut bollards and grotto-storerooms.

MODERN AGE

After the decline of the Roman empire (V century AD) due to the northern barbaric invasions, a long "blackout" occurred in the development of human civilization till about 1000 AD. The danger of attacks from the sea by the Saracens caused the abandonment of the coastal zones and their ports, which rapidly silted up.

One of the few inhabited coastal areas was the Venice lagoon, where an autonomous community had settled upon island marshes to defend from barbarians. Written reports of local shore protection works date back as early as 537 AD: wicker faggots were used to hold the earth dikes, reinforcing the sandy dunes formed from river supply, wind and wave action. The elastic but fragile willow branches for bank protection were then supplemented by the use of timber piles and stones, often combined in a sort of cribwork (Figure 7). Timber and rock revetments and groynes (forerunners of modern ones) have been used here until 1700 to halt beach erosion and siltation at the lagoon inlets, despite the limited durability of wood and the long travel distance for rock transport. The protection from the sea was so vital for the Venetian lidos since the early times that strict "environmental" regulations had been issued to preserve the littoral defences. Law documents of 1282 to 1339 state the prohibition to cut or burn trees from coastal woods; to pick out mussels from the rock revetments; to transit cattle upon the dikes; to remove sand or vegetation from the beaches and dunes; to export materials used for shore protection (Grillo, 1989).

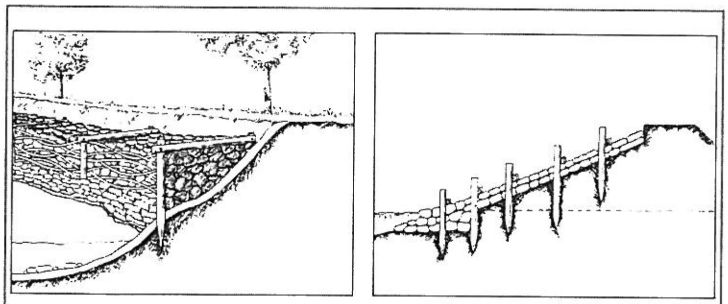

Figure 7 - Ancient coastal defences in Venice : rubble revetments within timber piled fences (6th to 17 th century)

Later in the XIVth-XVIIIth centuries the independent Venetian Republic became the main maritime power and the leader in the progress of hydraulic and coastal engineering (Marchi, 1992). The importance of the problems related to the preservation of the tidal lagoon, to the protection of the littoral barriers and to navigation, required the creation of a special Water Authority ("Magistrato alle Acque") managed since 1501 by elected hydraulic experts. Due to the high maintenance costs of the early coastal defences, in the 18th century the Authority sought for innovative solutions, which had to be experimented at the own risk of consultants and contractors (who were paid only after the effectiveness of the work had been proven...), such as: riprap revetments; gabions; smooth marble blocks linked with mortar and steel; flexible steel strips; stepped limestone blocks in regular pattern; various artificial elements to increase the roughness of the revetment slope; and even beach nourishment with sand dredged from offshore (just as it's being carried out today) ! Finally in 1743 the project of a massive seawall presented by a group of experts headed by the mathematician Zendrini was approved. The so-called "murazzi" are composed of a smooth heavy flagstone revetment supported at toe and crest with massive block walls; the average width is 12 m with crest elevation at +5 m MSL (Figure 8). The innovative technology was represented by the use of pozzolanic cement as effective bond between the rock-cut blocks, instead of the timber pile fencing. This seawall was built in about 40 years for some 20 km along the lidos and has lasted up to the present time, becoming a significant Venetian monument and a historical landmark of coastal engineering. However, some repairs after storms have been made with a rubble mound at the toe and recently with anchor piles and jet-grouting diaphragms.

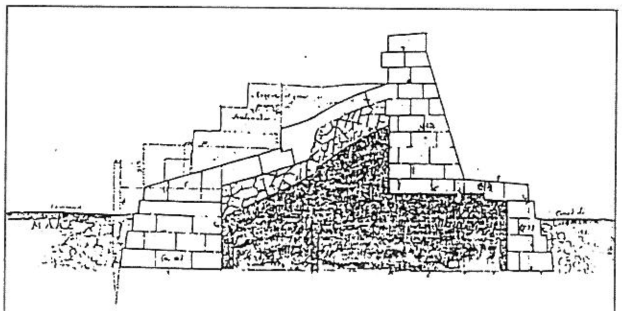

Figure 8 - Original design of the «murazzi» seawall by Zendrini in 1743

Outside Venice the modern age was characterized by a new integration of ports and cities, also for military defense purposes. Many new artificial harbours were created, such as at Amalfi, Naples, Leghorn, Palermo and especially Genoa. Here, on its exposed coast the old east breakwater was built with a fortified walled superstructure. The structure was so important for the city life that in 1245 it was declared as "Pious Work", which means that each citizen had to leave a legacy in his last will to support the breakwater maintenance.

The Renaissance actually took place in the XV-XVIth centuries, when a great technological progress was favoured by the development of mechanical equipment, such as for driving piles, dumping blocks and placing forms with pontoons. Even primitive techniques for breathing and working underwater were developed. Moreover the first dredging machines were developed (Figure 9) : in 1413 a Genoese inventor was hired by the port of Marseille. However, seabed levelling and cleaning was generally carried out by closing and drying out the harbour basin. Siltation was still the greatest problem of harbours. Regulated openings through the moles were still a favoured solution (Figure 10), but even fixed sheetpiles or mobile barriers made with wooden plates hinged to the seabottom at the harbour entrance were experimented by Tibaldi (a forerunner of the present floodgates for Venice...) also for military defence purposes.

In the Renaissance important developments occurred in architectonics, including harbour-city planning. The Italian

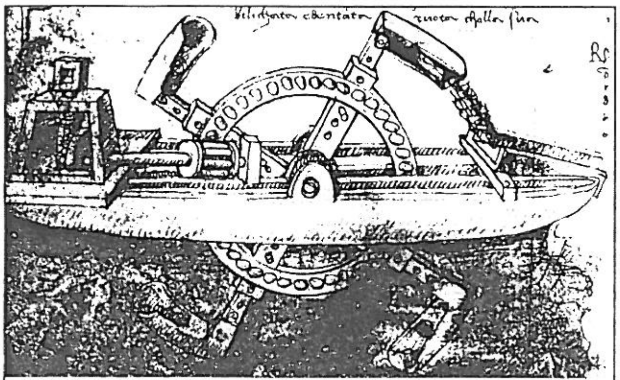

Figure 9 - Lagoon bucket dredger
(Di Giorgio Martini, 1475)

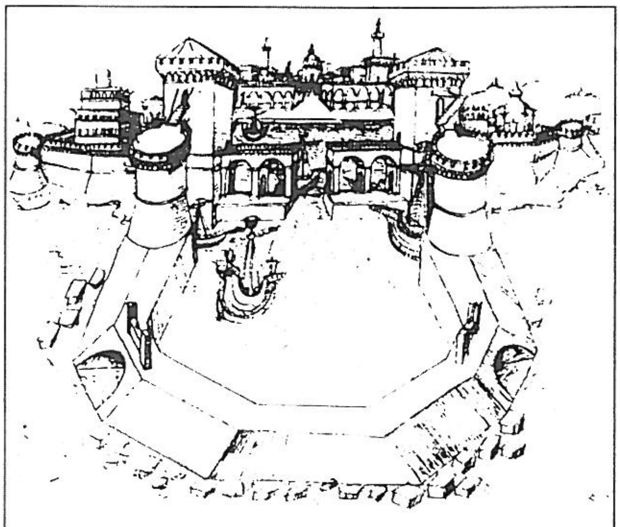

Figure 10 - Drawing of an ideal harbour
(Di Giorgio Martini, 1475)

engineers introduced a new design procedure, in which several alternatives are studied and the chosen solution is finally visualized by means of small-scale wooden models. The famous architect L.B. Alberti (1452) follows Vitruvius' technical recommendations for a nature-wise approach, even in the hydraulic design of coastal structures, such as mild-sloping breakwaters. The preferred artificial harbour layout had narrow entrances with curvilinear or even circular basin planshapes, to satisfy the ideal aesthetical/philosophical (as well as the hydraulic/functional/military) standards in a unitary vision of the fortified city-port. The "perfect" circular shape is also the one which encloses the largest basin area and would even resemble to a theatre since it can offer an attractive "show". Di Giorgio Martini (1475) even fixed the "golden measures" of the ideal harbour layout: a convex-shaped island breakwater, 100 m long, to shelter the 70-m-wide central entrance between two moles 70 m behind and a breakwater width of 25 m. However he also proposed a different layout with a long mole parallel to the coast, which would ease the defense of the fortified town, or a double nearshore entrance with a horse-shoe shaped breakwater with closable gaps for water circulation (Figure 10). The classic layout of Centumcellae harbour was considered as the model of the ideal city-port and even inspired Bernini's design of the famous columnates of St. Peter's square in Rome.

Moreover, the Renaissance period is marked by the important birth of the hydraulic sciences, including maritime hydraulics. In fact it was noted (Rouse et al, 1963) that "The Italian school of hydraulics was the first to be formed and the only one to exist before the middle of the 17th century". The most important innovations can be attributed to the eclectic genius of Leonardo da Vinci (1465-1519). By means of his well known experimental method, Leonardo was really the precursor of the modern coastal engineering science, anticipating ideas and solutions by more than three centuries. His notebooks exhibit some astonishingly accurate descriptions and graphical representations even of complicated flow patterns, also taking advantage of his extraordinary skill in painting (Figure 11). The variety of problems of hydrokinematics dealt with in Leonardo's notebooks is so vast that it would be hard even to enumerate in this review. Most phenomena related to maritime hydraulics are described in the 36 *folios* (sheets) of the beautiful Codex Leicester (1510). A full English translation is given by Richter (1970).

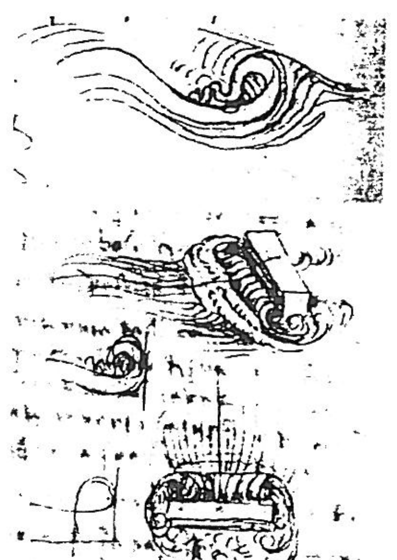

Figure 11 - Leonardo's drawings
of breaking sea waves
(Codex Leicester 1510)

Leonardo clearly explained the progressive nature of surface waves, the concept of relative wave celerity, wave shoaling and breaking, wave reflection and impacts at walls. Well ahead of times he attributed to the sea waves the prevailing role in the morphological evolution of beaches and defined the sediment equilibrium line. Leonardo was also probably the first to test several experimental techniques now employed in all hydraulic laboratories, such as flow visualization by means of both suspended particles and dyes; glass-walled tanks; movable bed models, both in water and in air (although he was aware of scale effects). He also defined the current circulation pattern in the Mediterranean Sea and the astronomical tides.

Leonardo contributed to harbour engineering too, particularly as related to the Adriatic "canal-ports" (eg. Cesenatico in 1502), where he accounted for the favourable effect of an inland large pond or artificial basin linked with the canal to increase the ebb flow and remove the inlet siltation. In the Codex Madrid Leonardo represented a design of a harbour at Piombino with a triangular planshaped island breakwater (to reduce wave forces) and two other small port designs. In the Codex Atlanticus, Leonardo gave a detailed survey of the port of Centumcellae and also examined the damage to the "Old Mole" of Genoa incurred during a great storm in February 1498. He even presented a utopic but fascinating spiral-shaped harbour plan, which was later proposed again by Gallaccini in 1603 (Figure 12). In his nicely illustrated treatise on sea harbours Gallaccini also gave a decalogue of prescriptions for a good harbour and breakwater design and described advanced floating equipment and original mechanical devices to work underwater and even walk over water ! (Simoncini, 1993).

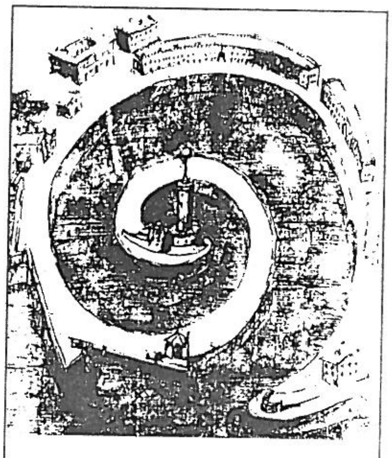

Figure 12 - Drawing of a spiral harbour by Gallaccini (1603)

Leonardo da Vinci was also involved in the design and construction of locks and is credited with having introduced the idea of locks in France, where he spent the last years of his life : still in use are the well known *Vincian gates*.

However, the first navigational lock had been already constructed in 1438-39 at Viarenna (Milan) by Fioravante da Bologna and Filippo degli Organi in order to ease the inland waterway traffic and particularly the transport of material for the construction of Milan's Cathedral. This simple but revolutionary idea of the short canal between two gates had a tremendous impact on the socio-economic progress of entire countries and was later used also for tidal ports, so leading to the growth of oceanic shipping in northern Europe, with a corresponding general decline of port activities in Italy. Viarenna lock is 38 m long and 6.2 m wide and could rise boats by about 3 m. It was dried in 1936 after 500 years of regular operation (Fassò, 1987).

However, in the XVIIth century "Italy was still the most prolific country for technical and scientific developments and its superiority lasted longer than supposed" (Clark, 1948). The technology of coastal structures was again receiving attention. The eternal debate about the choice between rubble mound or vertical breakwaters was still active. Based on his experience in the restoration of Civitavecchia harbour, Crescentio in 1607 recommended the use of irregular rock mounds (so-called "lost stones" system) with a pozzolanic concrete crown above sea level. Quite modernly he was suggesting not to use small stones to fill the porosity of the large rock armour and to let the sea waves naturally reshape the profile. In shallow calm waters the Roman system of cast-in-situ monolithic walls was preferred. For the deep harbour breakwater at Genoa an innovative composite design by De Mari was selected in 1638 after long discussions: a monolithic superstructure was cast in-situ within caissons sunk over the leveled rubble foundation at -4 m MSL, thus reducing construction times and costs and consequently the risk of storm damage (Faina, 1969). This new scheme had a large international resonance and was successfully applied by the English in high tidal ranges at Tangiers in 1663-83.

In the XVIII-XIXth centuries various Italian scientists, like Marsili, Montanari, Cialdi, Rovereto, Uzielli, Chelussi, Clerici, Cornaglia, Boscovich gave valuable contributions to the progress of oceanography and beach morphodynamics. Later on an important contribution to the theoretical analysis of wave kinematics was given in 1925 by the mathematician Levi-Civita who found the rigorous exact solution of the theory of irrotational oscillatory waves on infinite depth, which had been given with approximate solutions by Stokes and Raileigh. In the early decades of the XXth century detailed studies were also produced on the Italian shoreline variations (Toniolo, Marinelli, Merciai, Mori) and systematic surveys were promoted already in the 30's by the National Research Council (CNR).

Still the most important developments between 1850 and 1950 are observed in the technology of harbour breakwaters to be built in deeper and deeper waters. The state-of-the-art was summarized by Luiggi (1907) and Coen-Cagli (1936). An updated general overview is given by Borzani (1995) and Lamberti et al.(1994) with special reference to the typical composite structures.

The first example in Italy of the modern steep sloping breakwater armoured with precast blocks was the S.Vincenzo mole in Naples, built in 35 m depth since 1850 and followed by the Duca di Galliera mole in Genoa. Both breakwaters suffered severe damages and settlements, thus requiring reinforcement, typically achieved with heavier blocks, even placed in an original stepped profile *(Parodi* system).

These failures then promoted the revival of the classic vertically composite structure, first made with 50-t masonry blockwork (at Trapani harbour in 1896), later with a single or double column of weakly reinforced 220-t cellular blocks filled in-situ with mass concrete (at Genoa and Naples) and then with full-width solid cyclopean precast blocks (up to 450 t). However the famous storm failures that occurred at Catania, Genoa and Palermo opened new discussions and the first one led to new PIANC guidelines at the Congress in 1935.

The interest raised by these failures also promoted the modern scientific approach by means of theoretical and experimental studies and even prototype measurements. One of the first ever used full-scale monitoring systems of waves and pressures at walls was in fact installed on a 15-m-deep section of the Genoa offshore breakwater in 1932.

But the new construction technology of large monolithic cellular r.c. caissons allowed to overcome the fragility of the earlier vertical breakwaters. Prefabricated in yards the caissons can be floated into position and then sunk with water ballast and filled with mass concrete (as in the earliest applications at Alghero in 1915 and at Civitavecchia in 1931-36) or with incoherent material (as at Genoa airport breakwater in 1938). The construction of these latter caissons was made with a special fixed platform, which was the first industrial prefabrication equipment for maritime structures. Due to the War, the 42 caissons were abandoned offshore for 15 years without superstructure and were refloated in excellent conditions and reused as quaywalls (Figure 13).

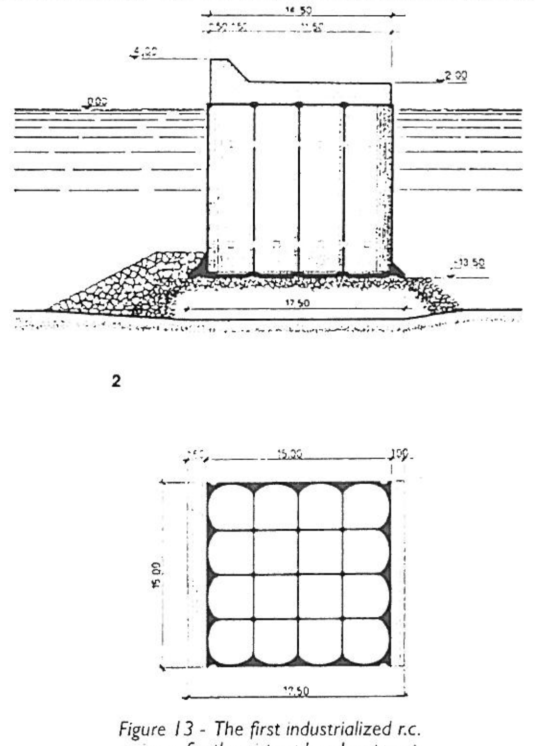

Figure 13 - The first industrialized r.c. caisson for the airport breakwater at Genoa (1938)

CONTEMPORARY AGE

The contemporary age began after WW2 when the first ICCE was held in 1950. Italy was just recovering from the destructive war. At the 18th PIANC Congress in Rome in 1953 an interesting book on harbour reconstruction prepared by the Italian Ministry of Public Works was distributed. Beside the necessary upgrading and deepening of the historical harbours, a few new ports have been constructed in the last 50 years, such as Genova-Voltri and Gioia Tauro (see PIANC Bulletin 94). New developments in port design can be observed in modern pleasure harbours and marinas, especially related to their environmental implications. Reference is also made to the illustrated book given to delegates at the ICCE (1992) in Venice, which describes the main new Italian projects of coastal engineering.

The technological evolution again progressed, especially in the traditional field of composite breakwaters, with the systematic use of cellular floating caissons, with larger size and more complex geometries, aimed at reducing wave reflection, toe scour, as well as forces and overtopping. The new caisson designs include seaward perforated walls and absorbing chambers, semicylindrical fronts and sloping curved and set-back parapet walls. An original example is the new breakwater

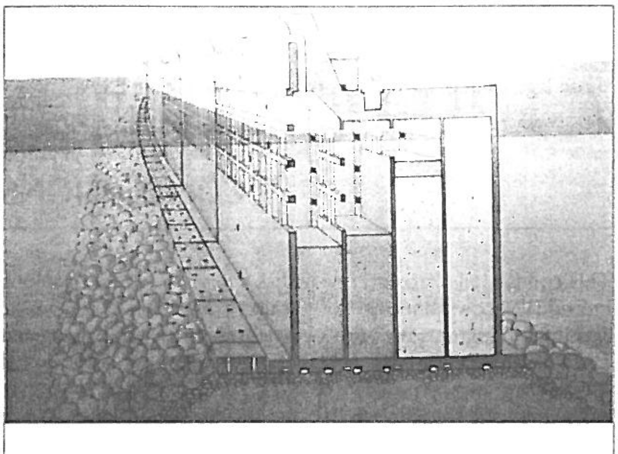

Figure 14 - The new instrumented perforated caisson breakwater at Porto Torres (1992)

at Porto Torres (Noli et al. 1995), which has also been instrumented, thus continuing the old Italian tradition of prototype measurements of wave forces on walls (Figure 14).

The efficiency of caisson breakwaters in terms of durability, safety and rapidity of construction, reduced maintenance costs and environmental impact is now being also recognized in northern Europe, as shown by the ongoing EU-funded MAST3-PROVERBS research project.

A unique example of pure vertical breakwater, a steel-piled structure with concrete screen, was also built in the early 70's to shelter an island-harbour at Manfredonia in 11 m depth. This solution was chosen due to the soft clayey silt foundation soil.

Progresses are also observed in the expanding field of beach morphodynamics and shoreline defense, due to the dramatic increase of erosion processes in the last 40 years. The importance of beaches for recreation and the new environmental concerns called for new systematic territorial policies. The earliest regional plans for coastal defence were issued in the north-central Adriatic area in the late 70's (Moretti et al., 1984). An overview of the state-of-the-art of Coastal Protection in Italy can be found in the proceedings of a national specialty conference, where engineers and geologists managed to meet together to report on the main case studies (Aminti et al., 1993). Original patented concrete elements (star-shaped piles or perforated-articulated blocks) have been experimented to defend beaches and enhance fish habitat. However, the numerous traditional "hard" structures (typically Italian are the rubble detached breakwaters, first designed by Lenzi at Salerno in 1905) are now being replaced by submerged barriers, for their favourable aesthetical and hygienic effects, often combined with a "soft" beach nourishment, mostly with sand quarried inland.

Actually early soft solutions had been already used in the 50's, when one of the first fixed bypassing plants was installed at Viareggio harbour. The bypass system was later modified and it is still operational with more flexible floating equipment (Fiorentino et al., 1985). Main examples of new "protected beach nourishment" projects are located at Ostia (Rome), Ravenna, S.Lucido (Calabria) and Venice Lidos (here using fossil sand dredged offshore). These latter works are the modern development of the historical sea defences and are part of the integrated Venice Safeguard Project. This large project also includes the design of the storm surge mobile barriers at the three lagoon inlets, which is presently undergoing E.I.A.

CONCLUSIONS

This condensed historical review has shown how the ingenious individual contributions of Italian hydraulic engineers, architects, mathematicians, oceanographers, geologists and even naval officers have helped the development of Coastal Engineering in a time span of over 2000 years. It is in fact acknowledged that Italy has been the leader country in the technological progress since the II century BC until the XVIIIth AD.

The scarcity of natural harbours along the Italian tideless coasts has forced the Romans and later the Italians to build exposed deepwater breakwaters (particularly of monolithic composite type) and hydraulically efficient port layouts, developing modern and creative design solutions well ahead of times. The earliest shore protection works were also experimented by the Venetians.

Despite the lack of large organized research centers and laboratories, Italian individuals have also contributed to the scientific development of this discipline, since the first advanced intuitions of Leonardo da Vinci to the present revival of theoretical and experimental research. The growing interest in Italy about the fascinating problems of coastal engineering is also revealed by the number of PIANC memberships (now the Italian delegation is the world largest together with USA's). In the wake of the ICCE'92 in Venice a new series of biennal national congresses, specifically devoted to coastal engineering, are taking place under the auspices of the Italian PIANC delegation. An overview of the main problems which are presently tackled in Italy (soft shore protection systems, restoration of old port towns, marinas, new monitoring networks, etc..) can also be found in PIANC Bulletin no. 94 (1997).

The growing pressure on the Mediterranean shores and on the delicate ecosystem of this semiclosed basin will require a more integrated and careful Coastal Management.The present trends in Coastal Engineering are again addressed towards harmony with the environment. Therefore it is worth remembering Leonardo's statement in Latin "*Ne coneris contra ictum fluctus: fluctus obsequio blandiuntur*", which means that "Nature should not be faced squarely and opposed, but wisely circumvented".

REFERENCES

Alberti L.B., 1465. "De re aedificatoria", G.Simoncini Editor, De Luca , Roma

Aminti P. and Pranzini E. (Editors), 1993. "The littoral defense in Italy" Ed. Autonomie n.34, Roma (in Italian)

Blackman D.J., 1982. "Ancient harbours in the Mediterranean", Int. Journal of Nautical Archaeology and Underwater Exploration, part 1 in 11.2 pp. 79-104; part 2 in 11.3 pp. 185-211

Borzani G., 1995 "Evolution of design criteria for harbour breakwaters" PIANC Italian Section (in Italian)

Clark 1948 "Science and Social Welfare in the Age of Newton", Oxford

Coen-Cagli E., 1936. "Italian Docks and Harbours" Journal of the Inst. of Civ. Eng., London

De la Pena J.M., Prada E.J.M., Redondo M.C., 1994. "Mediterranean Ports in Ancient Times". PIANC Bulletin no. 83/84, Brussels, pp. 227-236

Di Giorgio Martini F., 1475. "Treatise of Architecture, Engineering and Military Art", Ed Il Polifilo, Milano 1967 (in Italian)

Faina G., 1969. "Genoese harbour engineering in 1600" Istituto Italiano per la storia della tecnica, Giunti, Milano (in Italian)

Fassò C.A., 1987. "Birth of hydraulics during the Renaissance period" in "Hydraulics and Hydraulic Research: a Historical Review", IAHR, G. Garbrecht Editor, Balkema pp. 55-79

Fiorentino A., Franco L. and Noli A., 1985. "Sand bypassing plant at Viareggio, Italy", Proc. Australasian Conference on Coastal and Ocean Engineering, Christchurch (NZ), Vol. 1, pp. 441-451

Franco L., 1996 a. "Ancient Mediterranean Harbours: a Heritage to Preserve", Journal of Ocean and Coastal Management, Vol. 30, n. 2-3, pp. 115-151, Elsevier

Franco L., 1996 b. " History of Coastal Engineering in Italy" in History and Heritage of Coastal Engineering, ed. N. Kraus, ASCE N.Y., pp. 275-335

Grillo S., 1989 "Venice Sea Defences" Arsenale Editrice, Venezia (in Italian)

ICCE, 1992. "Coasts, harbours, lagoons protection works".(under patronage of the Italian Ministry of Public Works, Rome) 23rd ICCE, Venice

Italian Ministry of Public Works, 1953. "The reconstruction of National Maritime Ports" addendum to the Proc. XVIII PIANC Congress Rome (in French)

Lamberti A. and Franco L. 1994 "Italian experience on upright breakwaters" Proc. Int. workshop on Wave Barriers in Deepwaters, PHRI, Yokosuka, Japan, pp. 25-72

Luiggi L., 1907. "Maritime constructions at the beginning of the XXth century" Tip. Genio Civile, Roma

Marchi E., 1992. "Coastal Engineering in Venice", Proceedings 23rd Coastal Engineering Conference, ASCE, NY, pp. 4-39

Migliardi Tasco A., D'Arrigo A., 1965. "Italian Report at the XXI PIANC Congress" SI , II-6 (in Italian)

Marina Militare, 1905. "A historical monograph on ancient Italian harbours", (in Italian)

Moretti M., Pedone F., 1984. "Defence plan of the central Adriatic coast, Italy" Proc. Int. Symp. on Maritime Structures in the Mediterranean Sea, Athens, pp 4.133-142

Noli A., Franco L., Tomassi S., Verni R. and Mirri F., 1995. "The new breakwater and ore-carrier quay of the industrial harbour of Porto Torres (Italy)", Civil Engineering, London, February issue, vol. 108, pp. 17-27

Oleson J.P., 1988. "The technology of Roman Harbours", IJNA 17.2, pp. 147-157

Raban A., 1988. "Coastal Processes and Ancient Harbour Engineering". Proc. 1st Int. Symp. «Cities on the Sea - Past and Present», BAR Intern. Series 404, pp. 185-261

Richter, J.P., 1970. "The notebooks of Leonardo da Vinci", Dover Publ., New York

Rouse H. and Ince S., 1963 "History of Hydraulics", Dover, N.Y.

Simoncini G., 1993. "On sea ports: The treatise of Teofilo Gallaccini and the architectural concept of the harbour since the Renaissance to the Restoration", L.S.Olschki Editor (in Italian)

Testaguzza O., 1970. "Portus". Ed. Julia, Roma (in Italian)

Vitruvius M.L., 27 BC., "De Architectura", vol II-6; vol V-13 (in Latin) (in English in Morgan M.H. 1914, Cambridge or in Loeb Classical Library 1983, London)

KEYWORDS

Italy, Mediterranean Sea, Harbour Engineering, Coastal Engineering, Harbour Archaeology, Vertical breakwaters, Romans, Leonardo da Vinci, Venice, Renaissance, Port Architecture

MOTS-CLEFS

Italie, Mer Méditerranée, Ingénierie portuaire, Ingénierie côtière, Archéologie portuaire, Digues verticales, Romains, Léonard de Vinci, Venise, Renaissance, Architecture portuaire.

RESUME

HISTOIRE DE L'INGENIERIE COTIERE EN ITALIE

La longue évolution historique de l'ingénierie portuaire et côtière en Italie est brièvement résumée dans cet article. L'attention est attirée sur les innovations techniques des Romains, les avancées architectoniques et mécaniques de la Renaissance, les fascinantes découvertes scientifiques de Léonard de Vinci et l'expérience précieuse des ingénieurs Vénétiens et Gênois. Un bref aperçu des tendances actuelles clôture l'article.

ZUSAMMENFASSUNG

Geschichte des Küsteningenieurwesens in Italien

Es wird ein kurzer Überblick über die lange historische Entwicklung des Künsteningenieur- und Hafenbauwesens in Italien vorgestellt. Die Aufmerksamkeit wird auf die technologischen Innovationen der Römer, die „architektonischen" und „mechanischen" Entwicklungen der Renaissance, die faszinierenden wissenschaftlichen Entdeckungen Leonardo da Vinci und die wertvollen Erfahrungen der venezischen und genuesischen Ingenieure gelenkt. Zum Abschluß schließt sich ein kurzer Ausblick auf die gegenwärtigen Entwicklungstendenzen an.

RESUMEN

História de la Ingeniería Costera en Italia

Se resumen brevemente la larga evolución histórica de la ingeniería de puertos y costas en Italia. Se destacan las innovaciones tecnológicas de los romanos, los desarrollos arquitectónicos y mecánicos del renacimiento, los fascinantes descubrimientos científicos de Leonardo da Vinci y la valiosa experiencia de los ingenieros venecianos y genoveses. Finalmente se presenta un breve resumen de las tendencias actuales.

RIASSUNTO

STORIA DELL'INGEGNERIA COSTIERA IN ITALIA

E'presentata una sintetica storia dell'ingegneria costiera e portuale in Italia. Si pone l'attenzione sulle innovazioni tecnologiche dei Romani, gli sviluppi architettonici e "meccanici" del Rinascimento, gli affascinanti progressi scientifici di Leonardo e le esperienze degli ingegneri veneziani e genovesi. Si conclude con un breve esame delle tendenze attuali.