SEA DEFENCE WORKS IN VENICE
Attilio Adami, Civil Eng., Univ. of Padua, Istituto di Idraulica, Via Loredan 20, 35131 Padua Italy tel. +39-49-831452.

1. The problems of Venice and its Lagoon.

1.1 The System
The lagoon of Venice is one of the most important lagoon system of the Mediterranean Sea. It is located in the Northwestern part of the Adriatic and it is separated from the Adriatic by sand spits, tidal inlets and barrier islands. Throughout the Centuries its size, shape and structures have evolved significantly due to natural and human actions.

From documents we have, we know that, before man started to regulate the inlets and to protect the barrier islands, the system of sand spits, tidal inlets and barrier islands was quasi stable, due to the general sediment transport pattern of the area, which is SW-ward littoral drift Northeast of the lagoon, and N-ward drift South of the lagoon. Any way, the general trend of the evolution was walking toward a progressive silting of the entire lagoon.

The actual boundary of the lagoon of Venice was fixed two hundred years ago (see fig. 1) and it defines an area of some 550 km$^2$ (420 of which are covered by water, 90 by fish farms and 40 by embankments, coastal barriers, islands and land); the lagoon is presently connected to the Adriatic Sea by the port entrances of Lido, Malamocco and Chioggia and three hydrographic sub-basins may be defined, with surface area respectively of 276, 162 and 110 km$^2$.

Daily water exchange between the sea and the lagoon is about $3 \times 10^8$ m$^3$ (the fresh water input is two order magnitude smaller). The lagoon has an average depth of 0.6 m and a salinity in the range 28-36%. Many natural channels cross the entire area. The excursion of water level during an average spring tide is +/- 0.6 m.

Part of the lagoon is permanently submerged (shallows), part is permanently above water (islands) and part is submerged only by high spring tides (wetlands which constitute an important habitat for the characteristic lagoon flora and fauna).

Two main artificial canals, the Vittorio Emanuele (4 km long and 10-12 m deep) and Malamocco Marghera (15 km long and 12-14 m deep) were dredged in 1926 and 1968, respectively, in order to allow the passage of large vessels to the industrial area of Marghera.

At present, some 20,000 persons are employed in steel, chemical and other industries in Porto Marghera.

Agricultural drainage (a maximum of 650 m$^3$/s and an average of 30 m$^3$/s of fresh water from 1800 km$^2$ of heavily cultivated land) enters the lagoon at twenty points located along the inner border.
In addition to industrial and agricultural wastes, the lagoon has been receiving urban wastes from Venice (77,000 inhabitants), Mestre (240,000 inhabitants) and visitors (30,000 tourists in the average day).

1.2 The lagoon morphology

The history of Venice and its lagoon is the history of the difficult relationship between a coastal environment under evolution and the continual efforts of man to adapt the same to his changing needs (see fig. 2). From its first existence the city has had to fight the tendency to become filled with sediments brought by the rivers discharging into the lagoon; the tidal inlets were wide, shallow and constantly changing causing difficulties to the navigation; the low barrier islands were often breached during storm surges causing damages and loss of property and lives.

The existence of a large harbour constitutes the principal reason for many of the man-made transformations, such as the construction of the jetties and dredging of navigation channels. The Venetian carried out, between the 14th and 17th centuries, a complex series of works to make lagoon accessible to shipping of ever-increasing tonnage (for military and commercial reasons), as well as to extirpate the malaria caused by stagnant water. The course of the rivers Brenta, Piave and Sile were redirected directly in to the open sea.

Natural phenomena and human action has deteriorated the morphological characteristics of the environment as it is shown by the following facts occurred during the last century (see fig. 3):

- Loss of 50% of wetland areas;
- 0.3-0.4 m deepening of shallows;
- High siltation rate in the main channels;
- Disappearance of the net work of small channels.

These trends are common in many other coastal zones of the world. For instance in the Chesapeake Bay a comparable loss of wetlands has been documented and scientists are still analyzing the reasons (subsidence and sea level rise, lack of sediment inputs, water pollution, direct human actions such as dredging, fishing, and navigation).

In Venice the most evident sign of deterioration is the loss of wetlands and tidal flats which are essential constituents of the lagoon landscape and ecosystem.

The intertidal border of the wetland, together with the bottom of shallows at a depth of less than 1 m below mean sea level, are the areas of greater biological production, areas in which most of the nutrient load responsible for the eutrophication is recycled and made available to the grazing species of the food web.

The intertidal areas are also the feeding site of valuable wading birds. Therefore the deepening of shallows and the loss of wetland vegetation represent a serious problem for the lagoon not only in terms of the morphological integrity and landscape but also for the stability of the whole ecosystem.
Fig. 3
The input of sediment from the watershed is negligible. As shown in fig. 4, of the total amount of around 2 200 000 m³/year of sediments eroded from wetlands and shallows, 700 000 m³/year are transported into the sea by tidal currents, 1 500 000 m³/year are deposited in the channels; 400 000 m³/year of the amount accumulated in the channels are dredged and, till now, dumped into the sea.

As a consequence of sea dumping and tidal currents, the lagoon has a net loss of sediments of 1 100 000 m³/year.

The main causes of the morphological imbalance of the lagoon are:
- the lack of sediment input from the watershed and the littoral;
- the continuous dredging of main channels;
- the increased energy of waves produced by wind and boat traffic;
- the reduction of rooted vegetation at the wetland border and lagoon shallows due to the deposition of macroalgae produced during the frequent algae blooms caused by the eutrophication of the lagoon and due to anoxic condition of the lagoon bottom;
- the scraping and removal of bottom sediments due to the cultivation of manila clamps, the collection of worms for fishing, the conduction of fishing activities with illegal mechanical tools.

1.3 Relative sea level rise and flooding

Because of its low altitude the historical centre of Venice is exposed and vulnerable to flooding. From the beginning of the century the relative sea level rise in Venice has been about 23 cm (the sea has risen by about 11 cm, the land has sunk by 12 cm because of subsidence mainly due to the intense extraction of groundwater from 1950 to 1970).

This comparable small relative sea level rise brings about serious risks for Venice if we consider that the average spring tide excursion is about 1.1 m and in the very first decades of
this century St. Mark's Square was flooded 7 times per year while today flooding occurs on average, more than 40 times a year. While the antropic subsidence has been stopped in 1970 prohibiting the extraction of water, it has been agreed to design the defence work taking into account a scenario of 30-60 cm of global sea level rise over the next century. Floods in the Venice lagoon are now a recurring calamity; taking into account that the elevation of streets, shops, ground-floor flats in Venice is less than 0.8 m above mean sea level and that the range of a spring tide is +/- 0.6 m, even a rather frequent 0.3 m storm surge can cause damages if it occurs during a spring tide. Without a storm barrage system the inhabitants of Venice try to reduce flood damages by rapid action following the warnings of the Municipality Warning System: a 1983 system which provides reliable forecasts for a lead time not exceeding 3-4 hours. This time interval is often not enough for such actions as: to remove goods from ground-floors, redirect the city boat traffic, erect elevated pedestrian walk-ways.

2. Historic development of regulatory work

2.1 Intervention on the littoral

The lagoon of Venice is separated from the sea by a thin strip of land approximately 40 kilometres long interrupted by the three inlets of Lido, Malamocco and Chioggia. Since the XII century the defence of these coastal lands has been one of the dominant objective of the local authorities; but notwithstanding their efforts, the width of the islands between the inlets of Lido and Chioggia has decreased from many hundred metres in some cases to a mere 20-30 m. Since the XII century the coastal defence has been achieved reinforcing the dunes exposed to waves by different types of structures. The first solutions consisted of wooden piles fixed in the sand and tied together in faggots; the same structural idea was then used to border small areas which were then filled with small rocks. The coastal defences became increasingly bigger and stronger since the XVII century, when the first stretch of "murazzi" was built (see fig. 5). The murazzi are massive structures composed of heavy rocks and with a rather high wall along the entire coast.

![Fig. 5](image-url)
From the middle of the 19th century of the following very large mitigating measures were initiated:
- Very large inlet jetties were constructed in all three tidal inlets.
- Navigation channels were dredged.
- The old sea-walls at the barrier islands were reinforced.

Most of these works were finished at the beginning of the 20th century.

The introduction of the jetties blocked the littoral drift completely, causing accumulation at the North side of the Lido Inlet and at the South side of the Chioggia Inlet. This trapping of sand increased the general erosion along the barrier islands. Furthermore sand was accumulated in the northern and southern ends of the barrier islands in the lee areas of the long jetties, which further added to the general erosion. This erosion raised the demand for reinforcement of the sea-walls and groyne fields especially along the central part of Lido and Pellestrina. However, as no sand was supplied to the suffering beaches, and as the transport of sand away from the central parts of the islands continued, the beaches have been completely eroded away in these areas exposing the sea walls directly to the wave attack.

2.2 Intervention inside the lagoon
The continuous development in the lagoon area involved large changes during the last century, of which the most important are:
- Large reclamation works, mainly in the Mestre area.
- The construction of closed fish farms.
- Dredging works in the industrial zone and in the canals amounting to 19 million of m$^3$ during the years 1952-60.
- Dredging of the large Canale dei Petroli from Malamocco inlet to Mestre, 31 million of m$^3$ during the years 1961-69.
- Increasing pollution of the lagoon. (11 000 t/year of Nitrogen; 1 500 t/year of Phosphorus: 3 times the amounts that can be assimilated by the ecosystem).

2.3 The problems
This very drastic development within the fairly small and vulnerable lagoon area caused a series of problems to be more and more evident during the fifties. The most important environmental problems faced by the Venice community at present are:
- The frequent flooding of Venice.
- The deterioration of the lagoon morphology and ecology.
- The erosion of the barrier islands.
- The decreasing socio-economic conditions in Venice.

The present general approach to solving these problems is closely connected with the efforts to prevent the flooding of the City of Venice during excessively high tides. In 1983, with the Second Special Law for Venice, Consorzio Venezia Nuova (CVN) has been entrusted by the
Ministry of Public Works with coordinating the research, design and implementation of activities; its mandate includes also the construction of these projects. The main project involves the system of mobile gates at the lagoon inlets (see figs. 6, 7, 8). In 1989 the Consorzio Venezia Nuova presented a new, comprehensive approach for this intervention which focuses on the links between the construction of the mobile gates, the general action of re-establishing the equilibrium of the environment of the Venice Lagoon and regulating the economic activities within the lagoon. Other subsidiary projects are:

- the design and reinforcement of coastal protection works.
- the design of passive systems for local defence of urban centres against flooding (insulae project);
- the restoration of the lagoon morphology counteracting the on-going erosion of wetlands and the sedimentation in the canals by means of dredging and reconstruction of wetlands using the same material;
- the stopping and reversal of environmental decay of lagoon’s ecosystems, (sedimentation of sludge inside the city of Venice, algae blooms, etc.).

In the following the paper takes into account the projects of CVN for the defence from the sea with barrages of buoyant gates at the three inlets, together with the coastal defence works and the local defence against flooding of small urban islands (the insulae project, see fig. 9).

![Diagram](image-url)
3. Mathematical and physical models for the design of the barrier layouts

The optimization of the positions and layouts of the barrages at the three inlets required an intensive use of mathematical and physical models for investigating the impact of currents, wave, sediment transport on the new works and for minimizing the impacts of the barrages, when not in use, on navigation; water and sediment exchange between the sea, the lagoon and along the littoral.

The models have been calibrated and tested against good field measurements and through the comparison of their results.
In the Tab. I the models have been classified according to the problem areas together with other tools for solution such as desk studies and field measurements.

The presentation of the characteristics of the many models is not possible within the time of my lecture but some remarks can be done.

The present final design of the layouts with the positions of the barrages is completely different from the preliminary design of 1981.

At that time the knowledge about the maximum design wave was limited, therefore higher waves were assumed; public opinion was less concerned about water quality problems of the lagoon.

These were good reasons for positioning the gates inside the lagoon, as far as possible from the sea, and for considering acceptable the presence of wide lateral fixed structures that reduce the number of gates to be inserted at the three inlets but also cause a permanent reduction of the sea-lagoon water exchange and problems to navigation.

From the recent analysis performed by Consorzio Venezia Nuova in the REA project, the 1981 solution has been proved to be inadequate for its impact on navigation (the fixed structures caused irregular velocity distributions with separation zones, as resulted from the simulations with scale and mathematical models), and this adverse impact on navigation has been well documented with the mathematical model of manoeuvrability of ships taking into account various kind of ships, wind, waves, and the currents generated by hydrodynamic models.

The hydrodynamic simulations on the 1981 proposal confirmed the permanent reduction of the sea-lagoon water exchange and the modification of distribution of water fluxes in the main lagoon sub-basins, a modification not acceptable from the point of view of water quality and sediment budget.

The present solution for the gate layouts developed by Consorzio Venezia Nuova with the project of 1989 is greatly dependent on the results of a large number of simulations with scale and mathematical models of waves and currents. The process of simulation started considering a set of 31 alternatives for the three inlets: 16 for the Malamocco inlet, 8 for Lido, 7 for Chioggia.

After a first screening, 16 layouts have been selected and each of them submitted to the following kind of 20 simulations:

4 with an aerodynamic physical model to study load losses;
6 with a two-dimensional mathematical model to check water exchanges and to study flow ranges;
7 with a navigation simulation mathematical model to study ship transit through the openings and the locks;
3 with a mathematical model to study wave propagation within the port mouths.

A final set of 7 layouts have been chosen and submitted to 38 simulations.

Tab I can give an idea of the organization of the studies adopted for the different aspects of the problem.
**Tab. I. Problem areas and selected tools for solution of relevant problem in the design of the Venice barrage**

<table>
<thead>
<tr>
<th>PROBLEM AREAS</th>
<th>TOOLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description of the system</td>
<td></td>
</tr>
<tr>
<td>Storm surges</td>
<td>F, D</td>
</tr>
<tr>
<td>Wave climate</td>
<td>F, D</td>
</tr>
<tr>
<td>Shallow water effects</td>
<td>F, NWL</td>
</tr>
<tr>
<td>Water exchange</td>
<td>F, S</td>
</tr>
<tr>
<td>Sediment exchange</td>
<td>F, S,</td>
</tr>
<tr>
<td>Port traffic</td>
<td>D,</td>
</tr>
<tr>
<td>Functional design</td>
<td></td>
</tr>
<tr>
<td>Velocity fields</td>
<td>S2,3,</td>
</tr>
<tr>
<td>Wave penetration</td>
<td>NI</td>
</tr>
<tr>
<td>Sediment exchange</td>
<td>NVL,</td>
</tr>
<tr>
<td>Navigation</td>
<td>NI, NWS</td>
</tr>
<tr>
<td></td>
<td>NN</td>
</tr>
<tr>
<td>Structural design</td>
<td></td>
</tr>
<tr>
<td>Marine works</td>
<td>(not included)</td>
</tr>
<tr>
<td>Gates</td>
<td>(not included)</td>
</tr>
<tr>
<td>Bed protection</td>
<td>S4</td>
</tr>
<tr>
<td>Construction procedures</td>
<td>S2, S4</td>
</tr>
<tr>
<td>Operation</td>
<td></td>
</tr>
<tr>
<td>Closures of the gates</td>
<td>NS</td>
</tr>
<tr>
<td>Navigation control</td>
<td>NS, NN</td>
</tr>
<tr>
<td>Maintenance dredging</td>
<td>NVL,</td>
</tr>
<tr>
<td>Coastal protection</td>
<td>(not included)</td>
</tr>
<tr>
<td>Water quality control</td>
<td>(not included)</td>
</tr>
</tbody>
</table>

(F) Field measurements

(D) Desk studies

(S) Scale models (gate models are not included).
1. The entire lagoon, x,y scale 1:250, z scale 1:20
2. The three inlets of Lido, Malamocco, Chioggia, undistorted scale 1:60-70 for wave penetration, velocity field, discharges
3. The aerodynamic models of the three inlets, x,y scale 1:3000, Z scale 1:1000
4. Malamocco inlet with gates scale 1:30

(N) Numerical models

(NS) For storm surge forecasting
1. Statistical model of the effect of pressure and wind on water level in Venice
2. Two-dimensional hydrodynamic model of the adriatic sea
3. Limited area metero model for the prediction of pressure fields

(NT) For the propagation of the tide inside the lagoon
1. one-dimensional (IPROS)
2. two-dimensional finite difference SYSTEM20 (Danish Hydraulic Institute)
3. two-dimensional finite element (IPROS)

(NI) For the velocity field at the inlets
1. one-dimensional
2. two-dimensional finite difference
3. two-dimensional finite element

(NVL) For the velocity field along the littoral
1. two-dimensional finite difference

(NWL) For wave propagation in shallow waters
1. HISWA model of the development of action(energy) at each point on a regular grid in each direction sector (Delft Hydraulics)
2. SYSTEM20 (Danish Hydraulic Institute)
3. PORTRAY (Hydraulic Research - Wallinford)

(NWI) For wave penetration through the inlets
1. DIFFRAC (Delft Hydraulics)
2. PORTRAY (Hydraulic Research - Wallinford)
3. PHAROS Complete description of refraction and diffraction effects for 'mild slope' situations; directional spread and irregular waves by superimposition, effect of bottom friction, wave breaking, currents by iteration(Delft Hydraulics)
4. SYSTEM21 M8S (Danish Hydraulic Institute)

(NWS) For wave radiation stresses in modelling the sediment transport along the littoral
1. SYSTEM10
2. HISWA

(NNY) For navigation
1. Model for simulating the Stochastic process of gate closures and the delays to the ship traffic
2. Model for simulating the manoeuvrability of the ships crossing the new inlets
4. The gates

Detailed studies, physical model tests, mathematical models and a scale 1 to 1 model have been used to analyse and compare alternative solutions and to select the optimum gate for the protection of Venice from high waters.

Results documented in many reports elaborated during the past 4 years have demonstrated that the buoyant type flap gate (see figs. 10,11) is the best solution for Venice: it guarantees very high safety factors; it complies fully with the ecosystem of the lagoon and with the specific constraints imposed by the authorities; construction and maintenance costs are comparable with those of other possible alternative solution.

---

Fig. 10

---

Fig. 11

---
Preliminary design of the flood barrier with the solution has been completed in 1989. Basic design will be completed in July 1992.

Four barriers will be used to close the three lagoon mouths, during the storm surges, one at Chioggia, one at Malamocco and two at Lido (namely at S. Nicolò and at Treporti).

The depth and the width of each barrier have been established with the aim of preserving the present volume exchange of tidal water between the lagoon and the sea, and avoiding sedimentation.

The Chioggia barrier is located in 11 m water depth, 360 m wide and consists of 18 flap gates. The Malamocco barrier is in 15 m water depth, 400 m wide and consists of 20 gates. The S. Nicolò barrier is in 11 m water depth, 400 m wide and consists of 20 gates. Finally the Treporti barrier is in 6 m water depth, 400 m wide and consists of 20 gates.

The flap gates (20 m wide, and 22 to 29 m long) have basically a rectangular shape and are made of steel, protected passively by applying appropriate coatings, and actively by cathodic protection. They are housed in recesses in the foundation structures in such a way as to have their top face at the sea bottom level.

The connection of each flap gate to the foundation structure is made by means of two connecting/discharging hinge assemblies. This particular type of connection permits the disengagement and removal of the gate for ordinary maintenance and/or repair in a simple way and without using divers.

The development and the improvement of this particular connector/discharging hinge assembly was made possible by extensive experimentation on the prototype MOSE.

The assembly, beside holding down the gate (several hundred tons of forces have to be taken), permits two air passages, and connections for a device for measuring the position of the gate.

The flap gates are operated by sending in compressed air at appropriate pressures to displace and expel water from the inner compartment of the gate until the buoyant force is sufficient to raise the gate. Air inlet into the gate continues until the latter reaches its optimum operating angle.

An automatic regulating system will hold the gate at its design operating angle by introducing air and expelling water from the gate or by opening the exhaust valves and letting the air go out and the water go into the gate.

The gates, being made of steel, though coated and protected against corrosion, must be removed for maintenance at regular intervals. In order to reduce to a minimum the interference with navigation, the gates that must undergo maintenance will have to be removed and simultaneously replaced by upgraded ones in the shortest possible time without jeopardizing the safety of the operation. The most suitable equipment is a gantry crane moving on rails supported on the gate foundation structures and provided with all the necessary equipment and accessories in order to carry out all the operational steps with rapidity and without the need of divers. The gantry, when not in operation, is parked in a basin located behind the barrier abutment.
Adjacent to the gantry basin, the compressor station, the power house and other auxiliary buildings will be located. The control building will be over the abutment overlooking the barrier.

The foundation structures which house the flap gate are cellular type reinforced concrete caissons and incorporate service ducts where all the cables and pipes are laid, and rooms below the connector - disconnection assemblies where all the air inlet and exhaust valves are housed.

The caissons will be precast in a dry basin and then floated and towed to their final location. They will then be handled by pontoons or by a self-elevating platform which will control the gradual sinking of the precast elements obtained by filling some of the internal compartments with ballast water.

For each barrier 6 or 7 of these precast caissons will be sunk in sequence into a previously dredged trench.

Reliability and optimization studies have been conducted to define the gate system and mainly the air compression system and power supply and distribution system.

Each barrier should be provided with a compressor station and a locally produced electric power supply.

In addition to the local power stations, the plants will be supplied with power from the National Electric Company (ENEL) by means of two independent feeders. The reason for this high redundancy is to practically exclude the possibility of having a main common cause failure.

The overall Venice safeguard system will be completely monitored and remote controlled. A central control station will operate all four barriers overriding the local control stations. To increase reliability, all functional components will be hard-wire operated.

5. The insulae project

It has been demonstrated that the full protection of the city of Venice and of all other islands in the Venetian lagoon can be obtained only by mobile barriers at the lagoon inlets. Due to the low elevation of the land the full protection of the lands is achieved by closing the barriers 40 times per year with the present sea elevation; the number of occasions then increases rapidly should the sea level rise due to the greenhouse effect.

In order to reduce the number of closures, thus obtaining the minimum possible impact on the morphology and on navigation, local flood protections works have been envisaged around islands with lower ground level.

In many places the ground elevation is only 0.8 m and floods may occur up to 40 times per year hampering the normal human activities and increasing the degradation of buildings and monuments.
Generally, these places are the ones where the buildings and the monuments of greater historical value are located and where the space available between buildings or monuments and the margin of the island are very limited.

The characteristics of the local flood protection in these areas are highly dependent on the absolute need to maintain the existing artistic characteristic and value of the buildings.

The elevation up to which it is possible to erect a local protection is therefore not the same for all locations.

Conditions have been found where it is possible to erect local protections up to 1.3 - 1.5 m; for the full protection of these areas it would be possible to close the flood barriers only once per year.

In other cases (specially in the historical centre of Venice) the maximum elevation that can be protected with local interventions is only 0.9 - 1.0 m. Full protection of these other areas can be achieved by closing the barrier 7 - 15 times per year.

The above considerations show clearly that the main objective of local protections when coupled with the gates is to introduce a greater flexibility in the manoeuvring of the gates, reducing the number of closures per year.

The design and the construction of local protection present specific and difficult problems such as:

- at present Venice does not have a sewerage system and therefore waste waters are discharged directly into the lagoon through holes (pipes were not used in the old times).
  
  With local protection discharges in the lagoon have to be interrupted and diverted with a pumping system to a treatment plant (also to be built);

- also rain waters have to be managed in order to avoid internal flooding;

- as already mentioned, space for construction is minimal; it is not rare to work in a narrow strip only 1-2 metres wide;

- many historical buildings do not have foundations or the foundations are centuries-old wooden piles.

Before starting the works in the historical centre of Venice the construction of this type of protection has already started in places of less historical importance in order to make the necessary experiments and tests.

For instance, on October 1991 the insulae works have been completed at Malamocco, one of the first villages founded in the lagoon littoral of Lido in the XII century.

The village is crossed by small canals which are connected with the lagoon and today it is flooded approximately 40 times per year.

The works includes three small gates closing the canals at high tide, a continuous diaphragm wall against seepage and a pumping system for rain water.
6. The Coastal defence works

It is common knowledge that any rigid structure placed on the beach generates wave reflection, sand suspension, and sand dispersion in deeper waters and hence an increase in the rate of coastal erosion.

In this regard the interventions of the past were local solutions with the objective of protecting the land, without counteracting the lack of sand supply.

Now the intervention under development by CVN is beach nourishment (see fig. 12), a solution which intervenes on the very cause of erosion. On the other hand beach nourishment is compatible with the conservation of the historical structures of the murazzi and with the touristic use of the littoral.

The idea is very simple but its wide application introduces complex problems now are under examination.

The material suitable for nourishment has to be found in places where available equipment can economically operate without negative impacts on the coastal environment and great care has to be used in the selection of the equipment for discharging the sand on the beaches.

Due to the fact that the sand available for beach nourishment is very fine, the design of the structures for sand containment required extensive simulations on advanced mathematical and physical model coupled together.