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The MOSE in Venice Resilient Storm Surge Protections

Abstract

Venice and its lagoon, ecosystem that has always been in a precarious balance, which today is threatened by the increase in mean sea level. The event of November 1966 convinced every one of the needs to interrupt the connection with the sea to defend the historic center from high water. After in-depth studies, the solution was identified in the Mose, a system made up of rows of buoyancy gates; the preliminary project dates to 1981, but the works, entrusted in concession to the Consorzio Venezia Nuova, only began in 2003, delayed by the complexity of the regulatory context. The work came into operation for the first time only in July 2020 and it has stopped more than 80 flooding, including the extreme one of November 2022, second in the century record after November 1966. The Mose was designed for a technical life of 100 year assuming a sea level rise of 30 cm, while at the end of the century, due to climate change, the mean sea level is expected to rise more. Considering the time it took to put the Mose in action It is urgent to start thinking now to further solutions, meanwhile benefitting of the whole flexibility of the Mose system both for flood control and environmental protection by partial, and or, differentiated closures of the lagoon to stop flooding while limiting the impacts on port activities and lagoon ecosystem.

Keywords: High water, Mose, Buoyancy flap gates, Mean Sea level rise.

1. VENICE AND THE LAGOON, THE CONTEXT, AND ITS DYNAMICS

The Venice Lagoon occupies the Adriatic coastline between the mouths of the Brenta and Sile rivers, with over 500 km2 of surface, it is the largest wetland in the Mediterranean; it is an environmental asset of inestimable value and its protection is essential for the protection of the historic centers of Venice, Chioggia and smaller islands.

The lagoon is a coastal ecosystem divided into shallow basins (the *valleys* and the *basses*) that alternate with wetlands at higher altitudes (the *sandbanks* and the *velme*), periodically submerged, engraved by sinuous channels (the *ghebi*), enlivened by the alternating action of the tide twice every day. In this environment, where fresh and salt waters coexist, the real islands are few and are mainly located on the edges of the wrecks of river paleo-riverbeds; Most of the land surface, in all 5% of the total surface of the lagoon, consists of wetlands, raised, and artificially consolidated by the ancient inhabitants.

For many centuries, the sediments transported by the rivers that flowed into the lagoon or near it were able to compensate for the loss of sediments mobilized by tidal currents and the erosion of the shores caused by sea waves. If the action of man did not make itself felt heavily by diverting the mouths of the rivers, the configuration of the lagoon was the result of the fragile balance of opposing natural phenomena: on the one hand the constructive action of the rivers, on the other the demolition action of the sea. The tidal currents had the task of vivifying the internal waters and the coastal currents that of shaping the coasts and the estuaries with the tidal deltas: one internal and one external, submerged.

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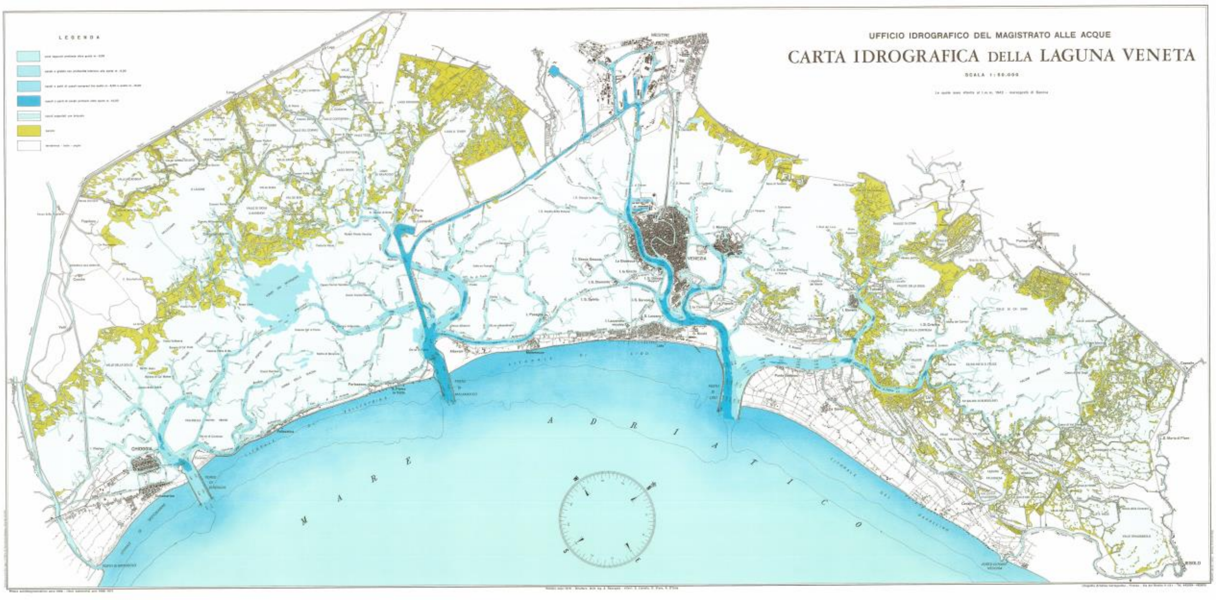

Fig. 1 – Hydrographic map of the Venice lagoon, year 1975
(Source: Min. LL.PP., Hydrographic Office of the Venice Water Authority)

The Venice lagoon is an environment of transitional waters in dynamic equilibrium, separated from the sea by slender coastal cordons interrupted by three port canals (the *inlets*). In this ecosystem, nothing is the result of nature alone: without human intervention, the lagoon would have disappeared long ago, in obedience to the evolutionary laws that govern the coastal areas occupied by transitional waters. The relationship of interdependence between man and nature has always been fundamental for the survival of the city, cultivated with wise foresight by the Serenissima, to the point of planning direct interventions on the ecosystem: the diversion of the great rivers that threatened to bury it, the defense works of the shores to resist the aggression of the sea, the dredging of the internal canals to guarantee freedom of navigation and later, After the fall of the Republic, the construction of the breakwaters at the inlets, to ensure access from the sea to ships of ever larger size and with this the economic life of the city.
Without continuous corrective interventions, the Venice lagoon is destined to turn into a deep bay with no internal channels; But these interventions are also a delicate problem, because morphologically inappropriate ones, such as the excavation or unconfined widening of port channels, can be harmful and accelerate this transformation.
The interaction between human activities and natural dynamics has no end; in these conditions, the search for a "*natural balance*", which has never existed in the lagoon, seems vain. Even the interventions to defend the historic center from high waters and to safeguard the lagoon environment conceived after the dramatic event of November 1966, undertaken by the Venezia Nuova Consortium and now finally in their final stages, are initiatives of adaptation to evolutionary dynamics: eustatism and subsidence.

2. VENICE AND HIGH WATER

High water in Venice is nothing new in recent years: as reported by the chronicles, flooding of the historic center has always occurred, even in ancient times (Canestrelli, 2009). The Venetian historian Marin Sanudo[5], in his "*Diarii*", dated November 16, 1517, wrote as follows: "*… having rained the night and so in the morning a lot, with a very great wind from Syrocho, in the following morning a little after the third hour the water grew very great in this land […] and in my court, which is*

[5] *Marin Sanudo "the younger" (1466 – 1536), a Venetian nobleman, son of a diplomat, wrote numerous historical works, including "the Diaries"; There are a total of 58 volumes written in the Venetian language, dealing with political, economic, military, but also everyday events.*

also high, the water was more than a step and a half high …“ [6]. The Sirocco wind is mentioned, a warm wind coming from the southeast, which in that circumstance (as often happens even today), was a contributing cause of the event.

What is new is that today the phenomenon of high water occurs more frequently than in the past. Astronomical and meteorological conditions that in the past did not cause exceptional tidal heights, due to the combined effect of eustatism and subsidence, now flood the historic center.
In 1962, with the congress "*The Venice Problem*" organized in San Giorgio by the Cini Foundation, the international scientific community became aware of the problems of Venice: there began to be talk of rising the average sea and the need for measures to defend the historic center and the coast. That congress gave rise to a first international committee of experts from different disciplines (the "*Comitatone*"), to study the problems of defending the historic center and safeguarding the lagoon. Among the scholars of the committee, there was a strong feeling of a threat looming over the city, but no one had really grasped the danger of high water.
A danger that manifested itself with the storm excited by the Sirocco wind, which on 4 November 1966 hit the Veneto coast, with significant waves up to 5 m high. In the historic center, the tide height reached the exceptional value (never exceeded again) of + 194 cm above zero of the tide gauge of Punta della Salute[7]. The sea penetrated the lagoon from Pellestrina, overflowing and damaging long stretches of the historic coastal defences, the "Murazzi",[8] which for three centuries had resisted the fury of the sea (Photo 1) (Dorigo, 1969) (Da Deppo, 2016). Regarding this dramatic event, the graph in Fig. 2 shows the tidal heights recorded by the tide gauge of Punta della Salute from 3 to 6 November 1966, distinguishing the meteorological and astronomical components (dotted curve).

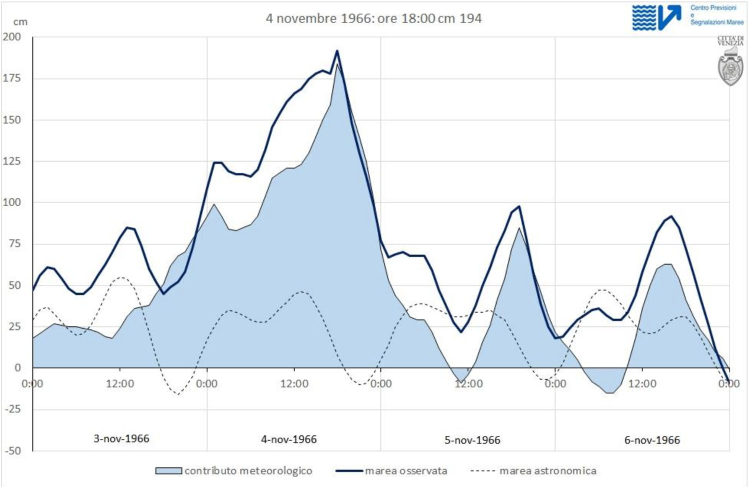

Fig. 2 – Tidal heights recorded by the tide gauge at Punta Salute from 3 to 6 November 1966 (Source: City of Venice, Tide Forecasting and Reporting Centre)

In the graph in Fig. 2 from 3 to 6 November the component of the astronomical tide was not at all exceptional and that it was rather the meteorological factors (sirocco wind and atmospheric depression) that determined the exceptional nature of the event.

[6] *“…shortly afterwards third...", shortly after nine o'clock in the morning; "... it was more than a pè and a half ...", she was over 50 cm high. At that time, Sanudo lived in Calle del Megio in Rialto.*

[7] *Previously, the maximums of 153 cm had occurred on 15 January 1867 and 151 cm on 12 November 1951, the latter event occurring in conjunction with the de f route. Po in Occhiobello (RO).*

[8] *The "Murazzi" were built by the Republic of Venice between 1744 and 1782; it is an imposing dam made of Istrian stone boulders that still defends the coast of Pellestrina from the aggression of the sea, tied together by pozzolanic lime from Roman ports, rediscovered by Zendrini, a Venetian mathematician, following a technical visit to Holland.*

Photo 1 – The Murazzi in Pellestina (4-XI-1966) **Photo 2 – Piazza San Marco (November 4, 1966)**

For over 24 hours the water that penetrated the lagoon, supported by the adverse weather situation, and hindered by the Sirocco wind, could not flow towards the sea and flooded the entire city. St. Mark's Square was submerged by more than 110 cm of water (Photo 2). The damage suffered by the city, the islands and the lagoon was enormous. The dramatic event of 1966 occurred in quadrature conditions, if it had occurred in a period of syzygy the level reached by the water could have been even higher.
The high tide of November 1966 is attributed a return time of 330 years; but recently it has been calculated that at the end of the century (2100), based on projections of eustatism and subsidence, the return time could be reduced to as much as 10 years (Marani, 2022).

3. MEASURES TO PROTECT AGAINST HIGH WATER

In the 1970s, the opinion spread that the high water in Venice was not just a natural phenomenon, that its intensification was a consequence of the changes that the lagoon had undergone in recent years and that therefore it should be brought back to a hypothetical "*primitive configuration*"; the barking of Porto Marghera, the closure of the fishing valleys and the Malamocco-Marghera canal (the "*oil canal*"), dug between 1964 and 1968, came under accusation. This erroneous belief, supported by environmental movements and prestigious intellectuals (including Indro Montanelli), gave rise to a sterile controversy: for some years discordant opinions were discussed. Finally, thanks to scientific research, particularly the contribution of Prof. Claudio Datei, it was possible to demonstrate that the thesis was totally unfounded.
In 1973 the fundamental Special Law No. 171 was approved, which declared the problems of Venice to be of "*pre-eminent national interest*" and established the principle of "*physical integrity of the lagoon*"; But 6 years after the tragic event of November 1966, no concrete measures had yet been taken.
In 1975 the Ministry of Public Works finally announced an international tender, to arrive at a project to ensure both the hydrogeological balance of the lagoon and the abatement of high waters in the historic center. Five competing proposals were received, but none were judged suitable. The Ministry then acquired the five projects and commissioned seven scholars to draw up a preliminary project, freely based on the proposals presented: they were Professors Augusto Ghetti, Enrico Marchi, Pietro Matildi, Roberto Passino, Giannantonio Pezzoli, Jan F. Agema and Dr. Roberto Frassetto.
Scholars came to the conclusion that in order to defend the city from high waters, it was necessary to resort to mobile barriers, to achieve the complete and simultaneous closure of all the communication gates with the sea at a predetermined guard level; But at the same time, they also argued that the closure should ensure the quality of inland waters and navigation in the harbor canals. In June 1981 the working group presented its outline project known as the "*Progettone*". This project included a series of safeguard interventions to be carried out in a coordinated manner, giving priority to reversible ones: the most important were the mobile barriers, to be built at the inlets of the port as a last resort. The technical solutions contained in the "*Progettone*" were not shared by everyone and the debate that followed divided politicians, administrators, intellectuals,

scientists, and technicians into opposing fields, delaying fundamental decisions for the progress of the work, decisions that were finally taken with serious delay.
In May 1982, with vote no. 209, the "*Progettone*" was approved by the Superior Council of Public Works; On that occasion, the Rapporteur Committee was composed of 36 experts from different disciplines, mostly from the academic world. The approval of the authoritative collegiate body, however, did not silence the controversy: for the development of the project began a long bumpy path that only twenty years later (June 2003) led to the start of the works.
To carry out the works, it was decided that the most effective way was to resort to the Concession and in 1984, with Special Law No. 798, the task was entrusted to a grouping of companies of national interest[9]: the Venezia Nuova Consortium (CVN). The CVN organized a complex technical structure in order to operate with a unified vision of the problems of the lagoon ecosystem; The Venice Water Authority[10], a peripheral body of the Ministry of Public Works[11], should have carried out a "*high surveillance*" action on the work of the CVN.
To design the interventions, the CVN made use of a multidisciplinary Technical Committee, composed of authoritative personalities from the academic world and experts in the various disciplines: professors Alberto Noli and Giovanni Borzani for maritime works, Eugenio de Fraja Frangipane for the environment, Arturo Colamussi for mechanical works, Luciano Jogna and Giuseppe Creazza for structures, Attilio Adami for hydraulic works and for studies with physical models.
The problem of safeguarding Venice was finally tackled in an organic way, in all its complexity: therefore, not only the hydraulic works and their performance, but also environmental protection, water quality, urban resilience, freedom of navigation, port activity, defense against high waters and storm surges. Every aspect of the complex problem of safeguarding could be tackled and solved thanks to the scientific support of the authoritative personalities of the Technical Committee.
The Water Authority, which was responsible for the "*high surveillance*" of the CVN, was assigned the tasks of planning and implementing the interventions based on the special legislation for Venice. The Water Magistrate had a very heavy task; in order to be up to the task, it should have been strengthened with the inclusion of new personnel with adequate technical and scientific skills and supported by the choice of authoritative and competent Presidents, independent of politics. None of that. The chronic inability to enhance the technical services of the state, combined with the strength acquired by the concessionaire, pushed the Water Magistrate on the path of a progressive and inexorable marginalization; a sad condition that ended abruptly in June 2014 with its suppression (Seminara, 2019).
In 1984 the CVN started a complex program of studies and experiments preparatory to the final design and started the drafting of the final project, known by the acronym REA (Rebalancing, Ecology, Environment), which took up the "*Progettone*" giving priority to the defense from high waters, and integrating it with a series of minor interventions in the historic center, along the coast and in the lagoon; among these, particularly significant, are the "*insulae*" and the "*artificial mudflats and sandbanks*". The first was aimed at protecting the historic center from medium-high waters (from 80 to 110 cm above the zero of the tide gauge of Punta Salute), the second to reconstitute the morphological structures typical of the lagoon, whose existence was threatened by the erosion of the seabed.

4. A LONG TIME FOR SUCH A COMPLEX AND CONTROVERSIAL WORK

[9] *The consortium companies initially were: Impresit of Turin, Girola of Milan, Grandi Lavori Ficonsit of Genoa, Condotte (IRI group) of Rome, to which was later added a grouping of smaller local companies: the Consorzio San Marco. Later, Impresit and Girola were replaced by the Construction Company ing. E. Mantovani of Padua.*

[10] *The Magistrate at the Waters of Venice was ideally the heir of the homonymous magistracy of the Republic of Venice created in 1501 and in itself to oversee the lagoon and suppressed in 1808 by the French occupying government; it was reconstituted by Law No. 257 of 7 May 1907, with the mission of governing the waters in the territorial area between the national border, the Adriatic Sea and the Garda-Mincio-Po alignment.*

[11] *Today the Ministry of Infrastructure and Transport (MIT).*

57 years have passed since the dramatic event that highlighted to the world the fragility of Venice and its lagoon (November 1966); 42 years since the preliminary project for defense against high waters ("*il Progettone*", May 1981); 20 years (May 2003) since the start of the construction work, which should have been completed 11 years ago at the latest (in December 2012[12]).
The well-known judicial events, the repeated measures of receivership of the CVN[13], the improvident suppression of the Water Magistrate, the removal of the large companies that controlled the CVN (now replaced by small local companies), the appointment of an extraordinary new Commissioner[14] and the more recent one of an additional liquidator Commissioner[15], have not facilitated the work of the CVN.
The Mose has been almost 95% completed for years now and the financial coverage of what remains to be done is assured; the phases of experimental management, testing and start-up of operation remain to be completed, before the final delivery of the work to the future manager: the Authority for Venice and the lagoon[16].
The complexity and cumbersomeness of national laws on public works and the environment, laws that protect different, sometimes competing, and often even conflicting interests, have contributed to delaying the end of the Mose's work. The great difficulty encountered in moving from the planning of the work to its realization, forced the CVN to operate in emergency conditions, with long execution times, creating a situation of monopoly and generating the condition that brought to corruption.

Foto 3 – Thames Barrier Greenwich (UK)

Foto 4 – Schelda Barrier (NL)

The Mose Although expensive in terms of construction and management, it appeared to be the only one able to meet all the conditions set by the Authorities, of which the main ones were: absolute invisibility, no obstacle to navigation, no interference with the tidal current, reversibility, flexibility, gradualness, and many others. The onerous nature of the project and the maintenance costs are a consequence of the conditions and constraints imposed.
None of the works created in the world and like the Mose They have been asked to meet such stringent conditions, nor to confront a public opinion that is so a priori partisan. London's barriers on the Thames (Photo 3), the storm barrier of the Eastern Scheldt (Photo 4), are valuable engineering works, built in time and with costs lower than the Mose, without apparent contrasts

[12] *The timetable attached to the Additional Act n°8067 of May 2005, set the end of the works at 31-XII-2012.*

[13] *By decree of the then Prefect of Rome Gabrielli in December 2014, Francesco Ossola and Luigi Magistro were appointed commissioners and extraordinary administrators of the CVN; the two, in April 2015, were joined by Giuseppe Fiengo. In March 2017, Luigi Magistro resigned and, after some time (November 2019), he was replaced with Vincenzo Nunziata, designated by the then Prefect of Rome Gherarda Pantalone; A useless measure, because in March 2020, he also resigned. From the way the story of the CVN commissioners has developed, it is clear how complex and troubled the conclusion of the work is.*

[14] *Due to the delay in the work on the timetable, by decree of the President of the Council of Ministers in November 2019, Elisabetta Spitz was appointed Extraordinary Commissioner, with the task of overseeing the completion of the Mose and interventions to safeguard the Lagoon.*

[15] *By decree law of August 2020, Massimo Miani was appointed liquidator of CVN and Comar company, pending the entry into office of the Authority for Venice and the Lagoon.*

[16] *Authority for Venice and the lagoon, established by Art. 95 of Legislative Decree no. 104/2020, converted into Law no. 12 of 3-X-2020*

with public opinion, but they certainly cannot be said to be works of negligible visual and environmental impact.

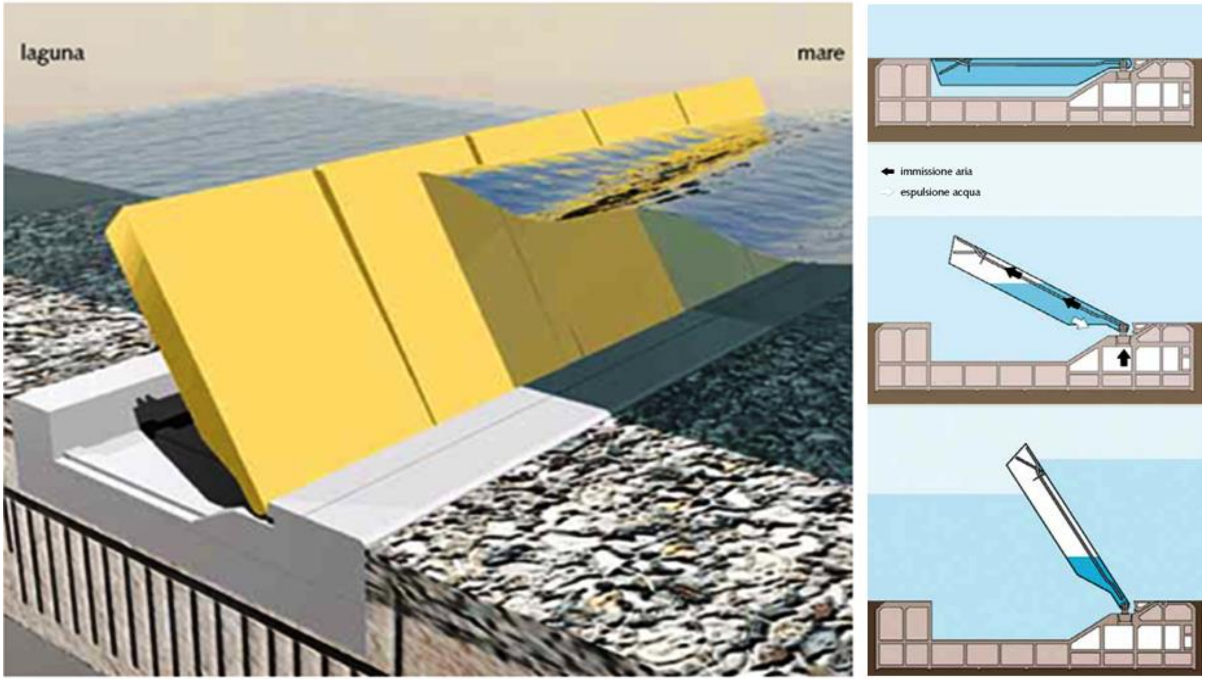

Fig. 3 Mose Storm surge barriers in Venice.

5. PRINCIPALI CARATTERISTICHE TECNICHE E COSTRUTTIVE

5.1 General Characteristics of Mobile Barriers

The acronym Mose, initially assigned to the Electromechanical Experimental Module, the mechanical artifice used to test the first sluice gate on site, now identifies the entire system of buoyancy gates, the modular elements that make up the 4 mobile barriers designed to temporarily interrupt the connection between the lagoon and the sea at the three inlets of the port of Lido. Malamocco and Chioggia, whose operation is inspired by the principle of Archimedes (287-212 BC). The CVN entrusted the design of the Mose to the company Technital S.p.A. of Verona[17], directed by Ing. Alberto Scotti; for the hydraulic works, Technital availed itself, among others, of the advice of professors Claudio Datei and Giampaolo Di Silvio.

The mobile barriers are composed of 4 rows of "*flap gates*", consisting of independent metal boxes, separated by a 15 cm air gap and tied to the bottom with two spherical hinges. In operation, the caissons are filled with compressed air for a variable mass depending on the desired final set-up, while the water is free to enter or exit. At rest, the rows of sluice gates are laid on the bottom, in special compartments obtained in the foundation caissons; without intermediate piers, they have no visual impact and guarantee freedom of navigation, without significantly reducing the exchange between the sea and the lagoon[18] and the maximum speed of the currents (Fig. 3).

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[17] *Technital S.p.A. was founded in Verona in 1964; It is active in the fields of hydraulic works, transport infrastructures, port and airport work, environmental recovery and design support studies.*

[18] *The water carrying capacity of the inlets is more than 96% of that before the works.*

Fig. 4 – Location of the four barrages at the three lagoon inlets Mose

The design of the Mose It was a very demanding challenge, because the technology used was completely new, all to be invented: at the time of the project, there was nothing commercial on the market that could be useful. The Mose it cannot be classified as a common civil engineering work: its design required the transfer to the building industry of technical specifications and tolerances typical of shipbuilding and the most advanced industrial processes; required the adoption of experimental techniques and the use of innovative high-performance materials, with innovative qualification procedures, sometimes decided during the work.

Foto 5 – Bocca di porto di Lido

Foto 6 – Bocca di porto di Chioggia

Foto 7 – Bocca di porto di Malamocco

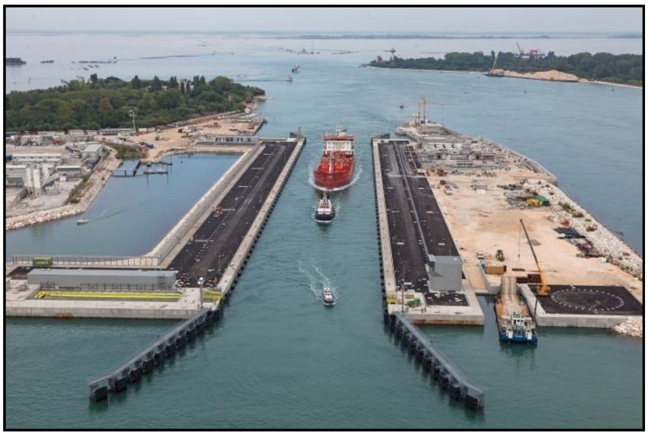

Foto 8 – Conca della bocca di Malamocco

Foto 9 – Le paratoie del Mose in sevizio

Foto 10 – Paratoie del Mose in servizio alla bocca di Malamocco

The arrays of sluice gates are flexible, designed to accommodate the wave motion without transmitting stresses on the foundations. The risk of sub-harmonic resonance has been rendered insignificant by an appropriate thickening of the gates to lengthen the periods of oscillation, distancing those of resonance from those of stresses.

The problem was thoroughly studied with numerical models and the solutions were finally verified with physical models at different scales, to prevent scale-dependent parasitic side effects.

The Mose system intercepts the port inlets of Lido (Photo 5), Malamocco (Photos 7 and 10) and Chioggia (Photo 6), through which the tide spreads into the lagoon (Fig. 4); the gates are divided into 4 independent rows[19] : Lido Treporti (21), Lido S. Nicolò (20), Malamocco (19) and Chioggia (18). In all, there are 78 active and 8 reserve gates, with 156 hinges connecting to the foundations and 312 independent air inlet/outlet ways (which guarantee a degree of redundancy 4).

Tab. I shows the dimensions and main characteristics of the four rows of sluice gates.

Tab. I – Mose system: characteristics of the four rows of sluice gates

[19] *The Lido inlet is divided in two by an artificial island.*

Bocche di porto lagunari:		Lido Treporti	Lido S.Nicolò	Malamocco	Chioggia
Canale portuale:					
Profondità	m s.l.m.	-6.0	-12.0	-14.0	-11.0
Larghezza	m	420.0	400.0	380.0	360.0
Paratoie:					
Numero	-	21	20	19	18
Lunghezza	m	18.6	26.6	29.5	27.3
Larghezza	m	20.0	20.0	20.0	20.0
Spessore	m	3.6	4.0	4.5	5.0
Peso	kN	1,680	2,820	3,300	2,890

The exercise of the Mose interferes with port activity: when the gates are raised, ship traffic entering and leaving the lagoon would be interrupted. For this reason, in Malamocco, the main access for commercial and cruise ship traffic in the lagoon, and in Chioggia, the main access for the fishing fleet, navigation locks have been built, which are expected to be completed by the end of 2023, to allow navigation even with rows of gates raised.

5.2 Buoyancy gates and operating conditions

The operating principle of the buoyancy gate is based on the alternation of filling and emptying its internal volume, with variable percentages of air depending on the desired final trim, while the water is free to enter or exit the container. In service, the hinged sluice gate on the bottom is a labile structure; To make it stable, a system of actions must always be balanced, such as to determine a moment resulting in zero with respect to the axis of rotation that passes through the hinges that bind it to the foundation. In this way, the final trim of the sluice gate is variable with the degree of filling, which is established by the operations center based on the forecasts of high water to be faced[20]. The design actions to be balanced, in addition to the self-weight, are the pressures of the air and water contained in the caisson and the sea-lagoon difference in height to be faced. In practice, once the starting tide situation (the hydrometric height that must be maintained in the lagoon) and the sea-lagoon difference in height to be faced (the height of the expected storm surge, based on the forecasts of the Tide Reporting Center) have been established, the volume of water and the mass of internal air necessary to ensure balance are calculated, based on the self-weight of the sluice gate and the expected final trim angle, taking into account the air condition diagram for its compressibility.

The level of protection in Venice, i.e. the minimum level required for the activation of the Mose, is 110 cm[21] which, with reference to the total area of the historic center, today corresponds approximately to a percentage of flooding of 12%. The system goes into alert 36 hours before the high water event and generally the closure maneuver begins when the level measured in the sea reaches 100 cm.

The closing time cannot be less than 45' in order not to generate annoying swell downstream and upstream of the sluice gates. In the lagoon, a level slightly higher than the closing level is always established, due to the contributions coming from the outside: filtration from air gaps, river inputs and rain. Level variations, even significant ones, can also occur locally due to wind.

[20] *It is sufficient to replace a volume of water of 330 cubic meters with air, to bring the Malamocco gates, which weigh 3300 kN, into conditions of incipient lifting.*

[21] *Value referred to the hydrometric zero of the tide gauge of Venice, Punta della Salute.*

Foto 11 – Sluice gate with the two male hinge elements.

Foto 12 – Jack-ups for transport on site and launching of sluice gates.

When a level of more than 150 cm or a duration of closure of more than 9 hours is expected, the closure takes place at the same time as the minimum of the tide preceding the event and in any case with the sea at an altitude of no more than 60 cm at the mouth of the Lido, so as to have a volume of lamination available in the lagoon, Always guaranteed of the astronomical tide excursion up to a maximum of 50 cm, to store contributions from outside.
The conformation of the gates is such as to produce a lifting thrust capable of coping with 3 m of difference in height with 1 m in the lagoon; For higher differences in height, the system is still effective, as the volume of overflow water is negligible (or in any case can be stored without exceeding the safeguard level, anticipating the closure at the minimum of the tide before the event).

5.3 Foundation caissons

The sluice gates are attached to the reinforced concrete foundation caissons, aligned on the threshold of the harbor inlets; each alignment is confined to the two ends, by the abutment caissons. The foundation caissons, which can accommodate two or four sluice gates, are multicellular concrete structures, laid within a trench dug into the seabed. Their shape varies according to the depth of the port channel: from the smallest in the mouth of Lido (60 x 36 x 8.7 m) to the largest in the mouth of Malamocco (60 x 48 x 11.6 m). The caissons are divided into cells (some watertight ones house the plants, others are filled with concrete or sand ballast) and are crossed by two parallel and independent pedestrian corridors, which connect the abutments. The tightness of the passing corridors, between body and body, is ensured by two sets of water-stop joints.
Each system or equipment, mechanical, electrical, hydraulic, is redundant at a level four, to ensure the maneuvering of the gates even in the event of failure of three of the four redundant components.
Not being able to operate directly on the bottom of the port channel, in order not to close the mouths to navigation with the shipyard, the foundation caissons were prefabricated off-site, brought to the site afloat and finally sunk in the trenches prepared on the seabed.
The latter operation is particularly delicate and complex due to the minimum tolerances allowed of 1 cm. Also noteworthy is the 140,000-square-meter construction site (Photo 13), built at the mouth of Malamocco to house the concrete batching and launching plants for the foundation caissons, with an average weight of about 230 kN, packed with 8000 cubic meters of concrete and 500 kg/cubic meters of steel. Due to the exceptional size of the works, the construction time (set-up, rigging, casting and maturation) of each caisson has varied from nine to twelve months.

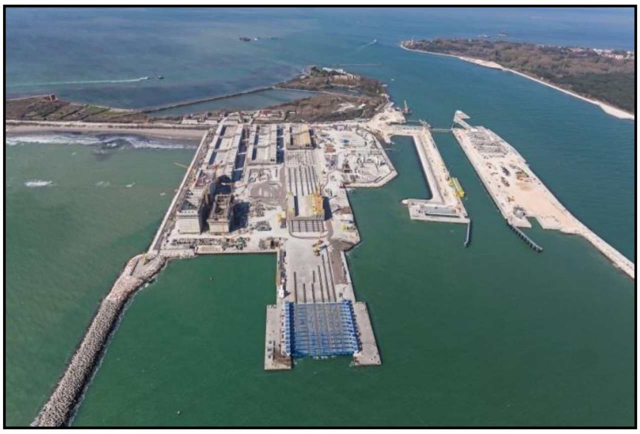

Foto 13 – Prefabrication site of the foundation caissons in Malamocco

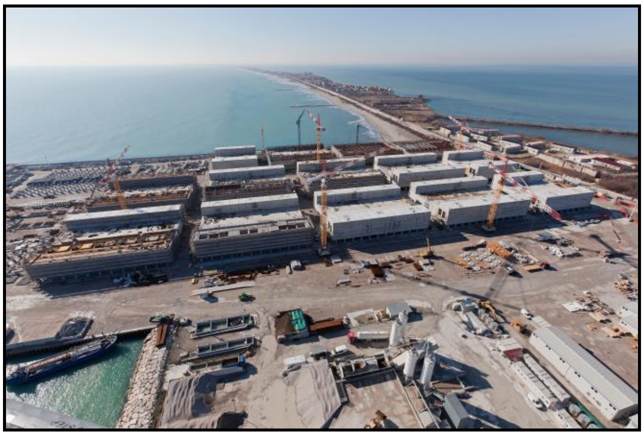

Foto 14 – Containers in the pouring and maturation phase

Foto 15 – Handling of containers on site

Foto 16 – Complete foundation caissons before being transported to the site while floating

The concrete used was produced by the company Calcestruzzi S.p.A.; an innovative product, designed specifically for this use, the result of extensive research carried out in the Italcementi laboratories in Brindisi and the University of Naples. Concrete was required to have chemical, physical and mechanical characteristics that were stable indefinitely, with a homogeneous and constant composition throughout the period of construction of the works and with an extraordinary resistance to the degradation of the marine, chemical (salts) and mechanical (waves) environment.

5.4 The connecting hinges

Each sluice gate is tied to its own foundation box with two hinges: there are a total of 156 hinges for 78 sluice gates. The newly designed "hinges", including the coupling and uncoupling connector (integral with the spherical hinge of the sluice gate) and the female connector (integral with the extrados of the foundation caisson) were made by the company Fip Industriale S.p.A..

Before moving on to production, FIP tested the behavior of the hinges and the grouting of the female element in the concrete, on full-scale prototypes: in fact, the "hinges" are a critical element for the functionality of the Mose and must guarantee a centenary lifespan (the female element), with five-year maintenance.

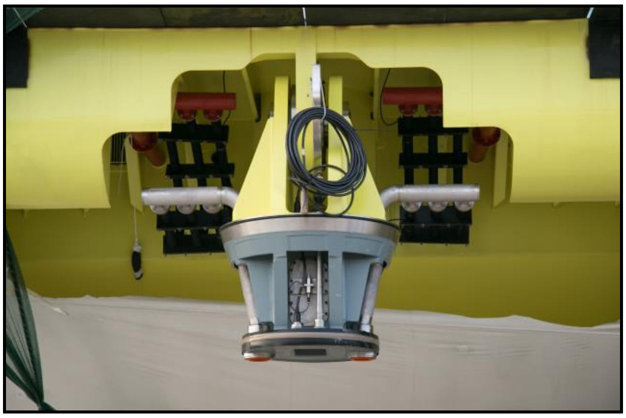

Foto 17 – Elemento maschio della cerniera.

Foto 18 – Foundation box with female elements (yellow).

The hinges have a steel structure resulting from the assembly of a connector element with the coupling system. The connector consists of a movable part weighing 10 tons, bound to the sluice gate (male) and a fixed part weighing 23 tons, bound to the foundation box (female).
The connection of the female part to the foundation is ensured by 10 post-tensioned anchor bars, arranged along the perimeter, and preloaded with a force of 3800 kN each. The tensioning and control of the anchor bars is carried out by acting from a watertight room in the foundation under the connector.
The coupling system is a complex device that performs the coupling between the moving part (male) and the fixed part (female), by applying a preload force of 3000 kN; The coupling allows the removal of the sluice gate to be carried out without the need for direct intervention by divers. The hinges/connectors also include the systems necessary for the operation of the gates: air and water pipes, electrical and mechanical connections, control, and measurement instruments such as inclinometers, all – as mentioned – with a level 4 of redundancy.

6. MOSE OPERATIONAL MANAGEMENT

Technical, economic, environmental and – for a certain period – also judicial difficulties have long troubled the realization of the Mose delaying the completion of the works, but did not prevent, starting from June 2020, its gradual commissioning, even if still in provisional operation.
On the night of November 12, 2019, a phenomenon of high water of exceptional gravity occurred: in the historic center the tide reached the level of 187 cm above zero of the tide gauge of Punta della Salute, causing serious damage; it was the second highest level since 1872, the year in which tide gauge records began (CNR-ISMAR, 2020), (Ferla M., 2020) (**ISPRA, CPSM, CNR-ISMAR, 2020)**tag.
The extraordinary event was produced by the concurrence of several unfavorable conditions: a peak of syzygy of the astronomical tide, a strong Sirocco wind that persisted for a long time in the upper Adriatic basin and a sudden depression associated with a local cyclonic disturbance, which generated wind gusts of over 100 km/h. A disturbance with unusual characteristics, also evidenced by the unusual shape of the ridge that occurred at 11 p.m. on 12 November, preceded by growth and followed by sudden decrease, caused by the localized and intense meteorological component, to be traced back to a tropicalization of the climate (Fig. 5).

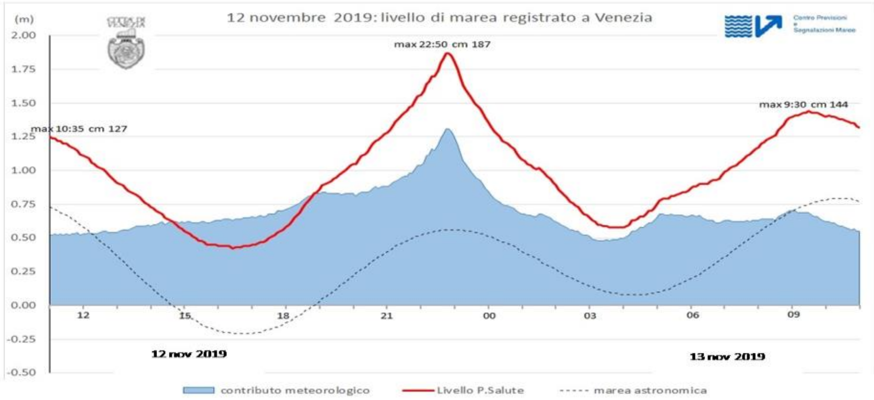

Fig. 5 – Tidal heights recorded by the tide gauge of Punta Salute from 12 to 13 November 2019 (Source: City of Venice, Tide Forecasting and Reporting Centre)

An anomalous event that was difficult to predict, which propagated along the Adriatic coast with exceptional rapidity: in the circumstance, all weather models had provided underestimated forecasts. The La Fenice theatre, St. Mark's Basilica and 80% of the historic center were flooded, foundations were damaged, gondolas and boats were torn off their moorings and dragged to the shores by the waves (Photo 19), extensive damage to businesses on the ground floors of the houses: that night the city relived the scare of November 1996.

Foto 19 – Public service boat pushed by the wind on the Riva degli Schiavoni

It was not an isolated event, because from 12 to 17 November, on four occasions the tide height in the historic center exceeded 140 cm. For high water, 2019 was a truly exceptional year: on 28 occasions the tide height exceeded 110 cm, with a total stay estimated at 50 hours in November alone (ISPRA, CPSM, CNR-ISMAR, 2020). Numbers that far exceeded the maximum values reached in the 150 years of previous measurements, which highlighted the effects of global warming in progress and how urgent it was therefore to put the Mose into service.
On that occasion, Venice proved to be unprepared to defend itself despite the fact that more than 50 years had passed since the disastrous event of November 1966, the Italian State therefore gave an important acceleration to the conclusion of the works by appointing an additional extraordinary commissioner: the arch. Elisabeth Spitz.
On 10 July 2020, 17 years after the official opening of the construction site, with a ceremony in the presence of national and local authorities, all 78 gates of the Mose They finally went into action. It was a simple "blank" test, to test the functionality of the systems: the gates were all brought to float with perfect synchronism. Despite the flattering result, some skeptics objected that the test did not give any certainty because the system was unstable and would not have withstood storm surges, and that in the circumstance "the well-known law of Archimedes had only been demonstrated".

Foto 20 – Mose at Chioggia in operation

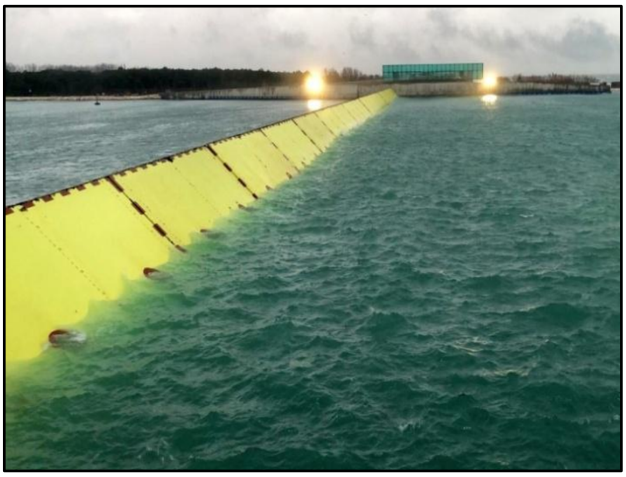

Foto 21– Mose at Malamocco on duties.

The first concrete operational test was carried out three months later, on 3 October 2020: on that occasion, the Mose successfully coped with a storm surge with gusts of Sirocco wind up to 54 km/h; At sea the level reached a maximum of 130 cm, but in the historic center, the level remained stable at around 70 cm for the entire six hours of closure of the inlets; the Mose For the first time he had kept the whole city dry!

Since then, the Mose It has protected the historic center from high water many other times, always coming into action with tide forecasts equal to or greater than 110, even for prolonged periods (such as uninterruptedly from 4 to 6 December 2020), often in adverse weather conditions.

Worthy of note is the high-water event of 22 November 2022 (Fig. 6), when the Mose it coped with a level that in the open sea at the CNR platform reached 173 cm, but values much higher inshore, at the outer piers of the inlets: 189 cm in Chioggia, 185cm in Lido S. Nicolò and up to 202 cm in Malamocco. In this circumstance, the mobile barriers remained raised for 23 consecutive hours, managing to maintain a level in the historic center, albeit variable, but always below 70 cm. A strong bora wind, which arose suddenly, caused a critical situation in Chioggia, where the level rose up to 110 cm, an altitude never reached until then.

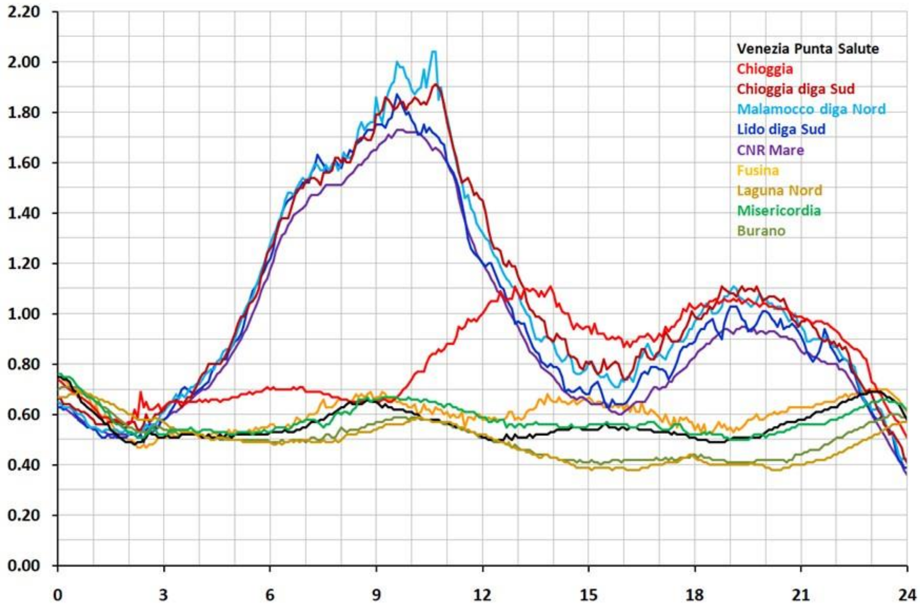

Fig. 6 – High water on 22 November 2022: closure of the Mose Tide gauge recordings of the Tide Forecasting and Reporting Centre of the City of Venice (Source: College of Engineers of Venice, "Mose and high waters")

From July 2020 to January 2023, the Mose he was lifted 20 times in the 2020/2021 season, 13 in the 2021/2022 season and 16 in the 2022/2023 season; A total of 49 high-water events, some of which involved multiple tidal cycles.

7. FLEXIBLE USE

The tool is highly flexible, so it is possible to use it not only to deal with the on/off closure of the inlets but trying to take advantage of all the management possibilities available, it is a new way of understanding the use of the Mose which must be deepened as different situations of exceptional tide arise from which to defend oneself. In the lagoon it will be possible to increasingly implement the knowledge and use of the tools available, evaluating the potential and monitoring the effects to allow the use of the defenses prepared in a flexible way, without creating negative impacts in the lagoon.
The exercise of the Mose It is flexible to the point of being able to counteract exceptional high water events with different configurations of mobile barriers, based on the characteristics of the tide event to be counteracted. Thanks to the independence of the elements that make up the mobile barriers, different defence strategies can be adopted, which can include the simultaneous and total closure of the three inlets, the differentiated closure or even the partial closure of one or more inlets. Differentiated and alternating closures are suitable for counteracting the consequences of climate change and can also be exploited in normal tide conditions, exploiting tidal currents to promote water renewal, with undoubted advantages for the quality of inland waters.

Foto 22 – Partial lifting of the Mose at the mouth of Malamocco

These potentials have been tested on some of the recent closures of the Mose, drawing useful information on exchanges with the sea and on the behavior of the waters in the lagoon basin in the face of temporary dissymmetrical closures of the port inlets.
On 29 December 2020, the Lido and Chioggia inlets were closed, while the Malamocco inlet remained open and the following day it was the turn of the Lido inlet only. Procedures that have also been tested with partial closures. performed in different ways and at different times, from 9 to 11 February 2021. In particular, on 9 February 2021, with a level of + 120 in the sea, the closure of the Lido port mouth alone made it possible to contain the tide in the historic center to + 100; this suggests that, by closing only the Lido inlet well in advance and keeping the other two inlets open to maritime traffic, under certain conditions it is possible in the lagoon to lower level values, compatible with the usability of the historic center.
To establish valid procedures and operating rules for differentiated closures of mobile dams, a few tests are not enough; Differentiated closure manoeuvres induce changes in the tidal currents in the

lagoon basin with potential effects on the transport of sediments across the channels (modest effects if compared to those induced by waves and bora winds on the shallow waters). In particular, the study is underway with mathematical models and with direct monitoring of the cumulative effects of repeated systematic closures of the Lido mouth alone (as the additional closure of Chioggia does not help to reduce the levels in Venice), to be able to close it safely.

8. EXPERIMENTAL RESEARCH

The most complex scientific research to deal adaptively with the new problems posed by the creation and management of the Mose have always characterized the action of the CVN, from the prototype of the sluice gate, to decide with which type of fluid to animate them (whether air or water), to the dredging and reuse of sediments in the protected nourishment of beaches, mudflats and artificial salt marshes, to the containment of differential subsidence of foundation caissons, to the multiple construction aspects of maritime works, civil and mechanical.

During the design activities, the Water Authority and the CVN always maintained close relations with the main European hydraulic laboratories that had already faced similar problems (Dutch: Delft Hydraulics, English Wallingford, and Danish Danish Hydraulic Institute), to compare experiences and design paths. In addition, for 18 years the CVN has been part of the international network of mobile barriers "*I-Storm*", and actively participates in the exchange of operational experiences on inspections and controls that have significantly increased the awareness on the design, operation, and maintenance of coastal storm barrier systems.

The need to develop the design through the extensive use of physical hydraulic models, as also requested by the Superior Council of Public Works in vote no. 209 of 1982, led to the important decision to resort to the support of the Experimental Center of the Ministry of Public Works of Voltabarozzo (PD) (Photo 23), active in the field of physical modeling of hydraulic works which, with a special agreement stipulated with the CVN, it was strengthened and operated to support the design of the protection works.

The Voltabarozzo Centre was equipped to the best experimental laboratories in Europe. In addition to the historic fixed-bottom general model of the Venice lagoon on a distorted scale of 1:250 (lengths) and 1:20 (heights) made in the '70s, the models of the mouths of Lido and Chioggia were also made on a scale of 1:60, the models of the mouth of the mouth of Malamocco on a scale of 1:60 and 1:80, by the company Protecno led by Prof. Attilio Adami.

Foto 23 – View of the center of Voltabarozzo

Foto 24 – Model of the bulkheads of Chioggia

Over time, experimental study techniques have evolved following the rapid transformations that have occurred in the field of modeling: mathematical models have benefited from the growth of the computing capabilities of computers and the algorithms linked to them, while physical models have made use of the possibilities offered by new sophisticated electronic measuring instruments. able to transmit an infinite amount of data to the computers that managed the tests. The two research tools have been used to the best of their ability: numerical models to study the flow fields in the lagoon basin, physical models to study the actions on structures.

One of the most delicate and complex investigation issues for the Mose studied in the Centre on models at different scales, concerned the operation of the arrays of buoyancy gates, their behaviour to wave motion and the complex problem of "resonance" (Photo 24).
In particular, with the support of brilliant young mechanical engineers from MIT, a mathematical model was created consisting of a two-dimensional hydrodynamic model of the port inlet associated with each second of calculation to the model of the motion of each fan gate of the array, for all 4 barriers considering the motion of air and water inside the gate, the equation of rotational motion under the action of the various current and pressure forces associated with the water levels, the acceleration of the mass of the sluice gate with its internal mass and the calibration factor of the added mass that is imagined to move in a way integral with the sluice gate. The model makes it possible to simulate the seismic wave that is triggered when the gates close rapidly together with the delay in the ascent of the sluice gate in the presence of strong current or wave motion, finally the model allows to predict the mass flow rate of air at 3 bar necessary to implement the planned maneuvers.

9. ADAPTATION TO CLIMATE CHANGE

The indirect effects of climate change are of concern to experts and the public. The Mose it was designed in the 80s of the last century to defend the historic center against tide levels above 110 centimeters above zero of the tide gauge of Punta della Salute; This eventuality – according to the designers' forecasts – should have occurred 3 to 5 times a year, implying closures of the sea-lagoon connections lasting a maximum of 4 to 6 consecutive hours.
Today, however due to the combined effect of eustatism and subsidence, the frequency of Mose It is destined to grow over time and the periods of closure to continue until the hypothesis, at the end of the century, of the possible complete and permanent closure of the inlets. The average sea level today is about 32 cm higher than it was at the beginning of the last century.
The graph in Fig. 7, created by the Tide Forecasting and Reporting Center of the City of Venice, illustrates the variation in the mean sea[22] from 1870 to 2022 and the frequency of cases of high water greater than or equal to + 110 cm (threshold value that provides for the intervention of the Mose) recorded in the historic center.
Taking into consideration the current century, limiting ourselves to the period preceding the entry into service of the Mose (2019), from the year 2000 to 2009 there were 45 cases with a tide height greater than or equal to 110 cm, while from the year 2009 to 2019 the number of cases more than doubled and rose to 95. In 2019, in 5 cases the tide height exceeded 140 cm; One of these (November 12, 2019) was the second most serious event ever, with 189 cm.
While acknowledging that climate forecasts appear uncertain because they depend on the hypothesized scenario, the warning signs of a progressive rise in mean sea level are unequivocal.
For Venice and the lagoon, the increase in the frequency of Mose it is a worrying prospect for the economic implications (usability of the port, even if it can have navigation locks, the port will become with regulated access), environmental (water quality and risk of anoxia in summer) and hydraulic safety (greater risk of malfunction), but not different from that which even the storm barriers in service in northern Europe are facing today precisely because of eustatism.
The Eastern Scheldt and Thames dams were designed in the 1960s with the prospect of at least a century's useful life; But today, after more than 40 years of activity, faced with the new and more onerous operating conditions, the need for adaptation or replacement is urgently needed for them too; in other words, the need for adjustments to restore the level of security progressively lost due to the rise in average sea level.

[22] *The average sea level is calculated by the Tide Forecasting and Reporting Center of the City of Venice, as an average of the maximum and minimum values recorded each year in the historic center. For the years 2020 to 2022, it is calculated with the values actually recorded in the historic center, even in cases of closure of the Mose .*

The Mose however, compared to other storm barriers built in the world, due to its modularity and multiplicity of arrays and flexibility of position, it has a high degree of adaptation to the effects of sea level rise that other barriers do not have, which bodes well for the reliability of the system even for a growing number of closures, At least until the average sea level is so high that it does not allow the lamination of high waters in the lagoon below the maximum level of protection (which will probably be increased from the current 110 to 130 cm), due to the lack of a low tide below threshold from which to start the closure maneuver.
Should the sea level rise beyond the 40-50 cm expected by the end of the century, Venice will still be one of the few most protected places in the Mediterranean for a long time and with a very intensive use of the system and therefore with a total of avoided damage well above the cost of construction and management of the system (effective and efficient operation is expected for at least 50 years even for the maximum growth scenario of 100 cm of sea level, with a number of closures that will reach 200-300 closures per year).
In any case, the level of protection may, if necessary, be increased or reduced by 20 cm in relation to the progress of the local protection works already planned or any other to extend the useful life of the work. It can therefore be said that the solution adopted will protect Venice for a minimum of 40-50 years and a maximum of over 100 years, providing us with ample time to develop the next protection system.

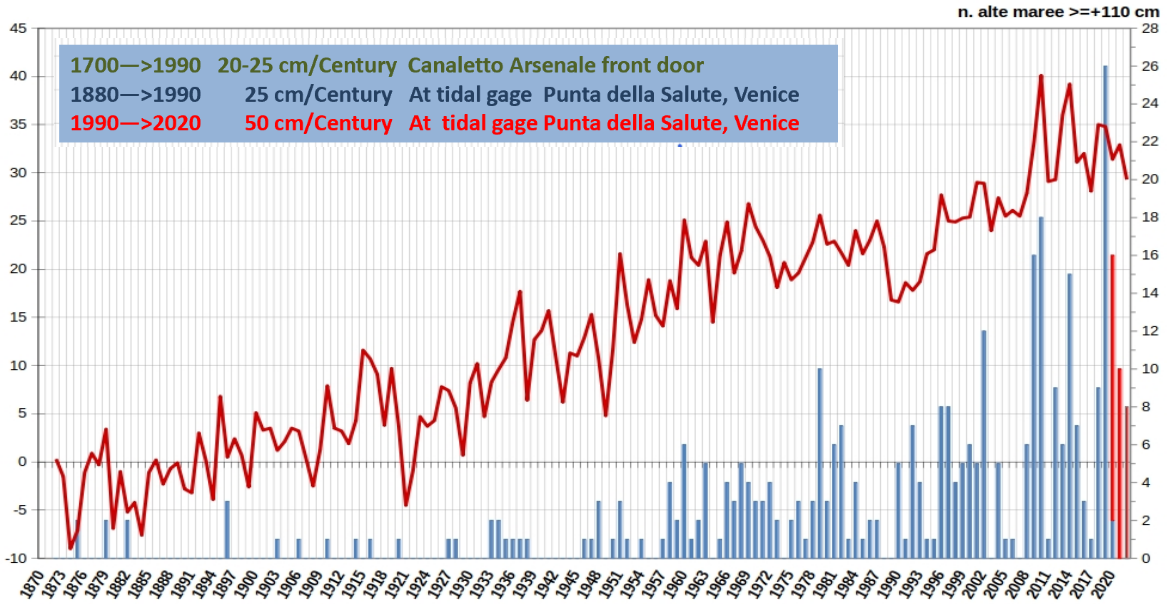

Fig. 7 – Tide gauge of Punta della Salute (VE): variations in the mean sea level and frequency of high waters greater than 110 cm, in red at sea with the Mose in operation (Source: City of Venice, Tide Forecasting and Reporting Centre).

According to Attilio Adami (Adami, 2022/2), the future for Venice could be that of the "*Venice Polder*", confined within embankments, with a level regulated at the historical heights of the eighteenth century, with a continuous flow of incoming seawater for hydroelectric production at the mouth of Lido with a difference in height of around 2 m and a terminal lift guaranteed by pumps on the North lagoon and Malamocco side. In this way, it will still be possible to have water suitable for bathing even without a complete sewage system, at least half upstream of the system.
Chioggia and Cavallino will also have to be equipped with increased local defenses together with the coasts, therefore with the need to supply large quantities of nourishment sand. The Veneto Region is moving along this line, which has commissioned Royal Haskoning to develop a coastal defense plan capable of coping with the growing rise in sea levels.

10. CONCLUDING REMARKS ON THE FUTURE OF VENICE WITH THE MOSE

The entry into operation of the Mose is emblematic of a possibility of rebirth that struggles to be recognized, accepted, accelerated, even in a context full of positive news of presences and methods among those who want to regenerate Venice in its lagoon: - the companies VeniSIA for innovation and VeniWhere for agile residence; - the growth in the international context of the three city universities: VIU, IUAV, and Cà Foscari, together with the Benedetto Marcello Conservatory and the Academy of Art; - the newly established Venice Foundation with 9 pillars of action[23], including those for youth residence in the city; - the expansion of the airport with the adjacent strategic centres; - the expulsion of the major cruise ships from St. Mark's Basin; - the undisputed worldwide relevance of the "*Venetian festivals*" but above all the events of the Art Biennale, - Architecture;- Cinema; -Music; - Literary prizes of the Venetian September.

By being able to consign to history today the complex scientific, technical, environmental and licit and illicit governance events of the Mose of Venice, which took place in the 56 years from 1966 to 2022, the year of the Mose's entry into operation, we want to conclude with the whish that the Mose may it become a symbol of hope in the nation's ability to carry out complex projects with a collective enrichment in knowledge, exemplary positive or negative experiences, effective practices of maintenance and management of the territory, which today we can perfect and adapt to new needs.

11. Call to Action

The history of the Mose teaches the value of informed persistence towards a precise goal; this practice can and must be applied to counteract the decline of the Italian country and beyond in the global context of a Humanity in multi-crisis due to constant acceleration: in the social sphere with the growth of wars, a clear indication of the lack of a sense of human interdependence between people and the environment; in the growth of information detached from experience, a growing amount of information that only algorithms will be able to synthesize, posing the problem of control[24]; in the increase in inequalities in access to the planet's resources, first of all global water and food, which we consume every year in the first six months, in a planet sick with greenhouse gases with all the dramatic effects of global warming: tropicalization of the climate, droughts, increasingly intense and recurrent floods, scarcity of water for agriculture and drinking with the rise in salt contamination, and increase in pandemics.

The defense of coastal cities from floods with systems such as Mose, studied and designed in an integrated way, well represents a metaphor of what can and must be done to mitigate the effects of climate change and social and environmental decline worldwide, taking care of the 95% of the earth's inhabitants less fortunate than us. We want you to start not only for the effectiveness of the Mose technical solution but for your belongings to beauty of Venice in order to stay focused with your resources in facing global problem together.

We, The Venice Community Lab, keep on connecting every individual (who looks with admiration to the Mose that is saving the beautiful Venice in a *Living with nature* restored lagoon) asking to him to join effectively the community network.

Adaptive Hospitality in Venice and Abroad, is the ongoing activity you can join for contributing to the development of the Water Community network .

23 *01.HYDROGEN, 02. ENERGY TRANSITION AND ENVIRONMENT, 03. VENICE CITY CAMPUS, 04.RESIDENTIAL, 05.SUSTAINABLE TOURISM, 06.VENISIA ACCELERATOR, 07.SOCIAL INCLUSION, 08.CULTURE OF LEGALITY, 09.CULTURAL PRODUCTIONS AND INNOVATION*

24 *Today's news is that drones can travel autonomously in search of targets, leaving it to humans to confirm or not the target, but until when if the threat grows and to survive, they will have to strike first?*

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