# WATER CIRCULATION IN COASTAL MARINE AREAS - CASE STUDIES

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**Abstract** – Taking into account the difficulty of water circulation within the marinas and over the defence works, an integration to the enquiries to support the technical solutions found is required, by means of the implementation of experimental tests of a three-dimensional physical model. The aim of the experimental survey carried out in the wave system basin of the University of Campania "Luigi Vanvitelli" was that of assessing the water circulation intensity behind the works of Salerno and Ischitella coast and inside Fiumicino port, Manfredonia port and Castelvolturno port. Due to the remarkable linear development of the works, their behavior was studied through the realization of a Froude scale model. The water circulation over the defense works was evaluated with reference to the storms, while inside marina with reference to the action of the jet mixers. The results of tests show that water circulation is ensured by jet mixer inside marina and by storms behind defence works.

## Introduction

The presence of pollutants (hydrocarbons, oils, floating solids, organic substances, etc.) in coastal marine areas is an environmental problem that must be properly studied, both in the design phase and in the management program of the sea defence works [8]. Therefore, it is necessary to verify that there are exchange water volumes through the presence of a motion field with appropriate characteristics. In most cases, the water exchange is ensured by natural actions and, in particular, by the tidal currents.

The most frequent cases to analyse are represented by the port basins and by the basins over the coastal defence works. In the case of port basins, due to the complex geometry of the port and to small amplitude of the tidal wave, the natural circulation is ensured only for the most external areas of the port. So it is required the use of a forced circulation system using electromechanical equipment (submerged pumps and mixers) with suitable characteristics positioned inside the basin.

Emerged coastal defence works although guarantee a greater dissipation of the incident wave energy in the presence of storms, it can determine, in all the other weather conditions, a mitigation of natural water circulation with stagnation phenomena. To mitigate this condition are often realized submerged structures that guarantee adequate circulation within the protected basin and therefore adequate water quality even if it is necessary to verify its effectiveness in terms of coastal defence.

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Therefore, for the above cases an integration to the enquiries to support the technical solutions found is required, by means of the experimental tests on a three-dimensional physical model.

In this paper, we report the results of some experimental studies performed using the wave tank of the Maritime Hydraulics Laboratory of the University of Campania "Luigi Vanvitelli" [2]. The wave basin is 15.70 m wide and 12.45 m long and has an operating water depth, h equal to 0.56 m, kept constant for all the tests. The concrete bed slope is fixed at 1:20 for 10 m length. The bed in the basin is formed by sorted well sand with $D_{50}$=0.20 mm and $\gamma_s$=2.60 t/m$^3$. Waves are generated by 30 piston type wave paddles that are capable of generating regular and irregular waves with several wave attack angles.

In particular, the studies carried out for the evaluation of water circulation will be described under the action of forced circulation system positioned in the basins of the new tourist ports of Manfredonia, Castel Volturno and Fiumicino; similarly the solutions analysed for the water circulation evaluation over of the Salerno and Ischitella defence works will be examined.

Experimental tests were conducted on Froude models [1;7]. The water circulation was evaluated over the defence works with reference to the storms, while inside marinas with reference to the action of the jet mixers. For each test performed, the water circulation analysis was done using velocimeter and colourful floating particle, which allowed verifying the technical solution efficacy with a qualitative-quantitative approach. Figures 1 and 2 show the scheme of the two cases studied.

## Experimental Setup

The wave basin is 15.70 m wide and 12.45 m long. The operating water depth, h, ranges from 0.40 m to 0.60 m. The fixed concrete bed slope is 1:20 for a 10 m length. The bottom material in the basin is formed by well-sorted sand with $D_{50}$=0.20 mm and $g_s$=2600 kg/m$^3$ (Figure 1).

A wave-generator with a non-reflective generation system is used to produce right angle and oblique incident waves using a snake-front piston-type paddle system that has 30 wave-paddles and actuators. Wave absorbers are used to reduce the waves reflected from the side and rear walls of the wave basin. A wave-absorbing beach is used to reduce the wave energy on the shore side. The wave generation software used for controlling the paddle system is AWASYS, developed by Coastal Engineering Laboratory of University of Aalborg. The absorbing wave system is operated by non-recursive linear digital filters working in real time [6]. In particular, the values of wave height are between 0.015 m and 0.25 m, the wave periods between 0.6 s and 2.0 s for water level varying 0.40 m and 0.60 m. The wave propagation angles vary between 0° and 30° with directional spreading, s, between 0–40. Wave heights are measured by 30 resistance probes with a sampling rate of 20 Hz. Measurements of beach profiles and bathymetric profiles are made with a Conventional Profiler M5L Laser setting on the carriage (Figure 1 [6]). Flow field measurements are carried out by an ultrasonic Doppler Velocimeter with a sampling frequency equal to 20 Hz.

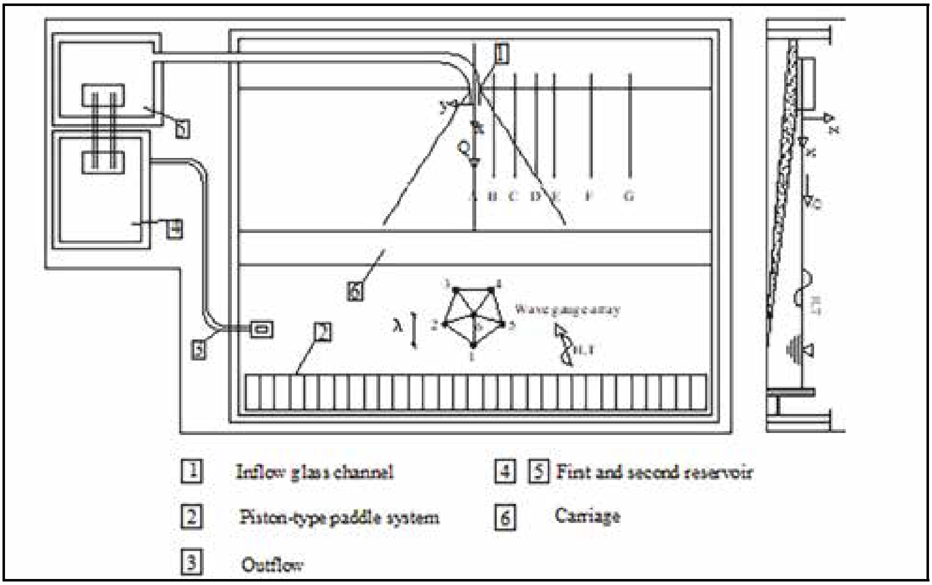


Figure 1 - Maritime Hydraulics Laboratory of the University of Campania.

## Water circulation within the marinas

### Port of Manfredonia

The new marina at the south-east of the Italian peninsula Ionian coast, is located in a strategic position for south Italy both marine and land traffic (41° N, 15° E). The marina will be realised along the coastline included between Barletta city and headland of Gargano. The highest and most frequent waves interesting the coastline come from the sector 50° N and 140° N. The marina is protected by two emerged breakwaters converging to a central straight entrance with head section depths to -6.50 m sl. The east breakwater is located near to old commercial harbour while the seaward breakwater is positioned at variable depths between -6.00/-7.00 m sl. The trunk section breakwaters are constituted from rock rubble mound [3]. The basin has an almost square shape with a triangular shape entrance. Inside of the basin, two rows of five piers are planned, with regular spacing. The seabed, inside the port basin, slopes gently from the water depth of about -2.50 m sl up to -6.00/-6.50 m sl near the entrance. The slope of the seabed is constant and equal to 0.015 inside the basin, to then decrease to 0.005 in the entrance where it is almost flat.

The physical model is equal to 1: 120 (Figure 2) to reproduce the entire port basin. The trunk section breakwaters are constituted from rock rubble mound with the weight calculated in according to the Froude's scale; the harbour quays are done by the steel sheet while the floating piers with cork sheet. Particular care it has been taken reproducing the bottom bathymetry, as it strongly influences the motion field within the basin.

To ensure an adequate exchange water volumes within the basin, a system of submerged agitators, arranged in the manhole covers inside the piers, are designed. The agitators are capable to do the jets characterized by an axial speed of approximately 0.40 m/s. This system was reproduced in the physical model by means of 2.4 cm diameter jet mixers. Each mixer is located at the end of a 30 cm long tube with a diameter of one inch, immersed in a water depth equal 6 cm. It was suitably calibrated so as to determine at the opposite end a current with an axial component of the average time speed of approximately 3.65 cm/s at a distance of 10 cm from the mixer. This value is equal to about 0.40 m/s in the prototype, in agreement with the project velocity. Six mixers have been installed, three of which are located along the quay next to the seaward breakwater and three along the east breakwater. From the preliminary tests, the mixers system was more effective in the withdrawal of water from inside of port basin; instead the inlet of the water from outside basin to inside itself was less strong. The test has been verified with reference to only one of the mixers, located inside the central pier (Figure 2). Coloured floating particles made of cork have been introduced to visualize the motion field induced by the mixer. In Figure 2 it is shown how already after about 1500 s (corresponding to about 5 hours in the prototype), all the tracer particles have been suctioned near the mixer.

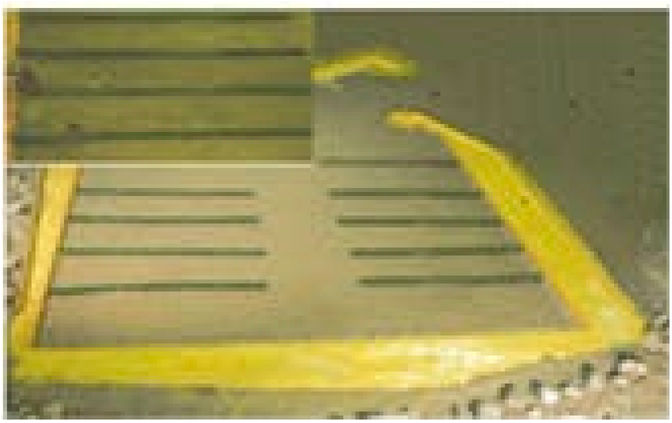

Figure 2 - Marina of Manfredonia; Mixer inside the central pier.

**Port of Castel Volturno**

The Pinetamare Marina near Castel Volturno city (13°58′39″ E, 40°58′29″ N) is a structure placed respectively to 7 km and to 1 km south of the mouths of the Volturno River and the RRLL canal, along the Domitia coast in the southern Gulf of Gaeta. The port is characterized by two breakwaters done by natural stone. The water volume of the basin is approximately 1 800 000 m$^3$.

The model of the port basin was reproduced in scale 1: 135. The trunk section breakwaters are made with limestone stone of suitable size; the piers has been reproduced with steel sheet while the quays with floating cork sheets (Figure 3). To determine a water exchange within the basin, five submerged jet mixers have been installed along the quay and near the breakwaters (Figure 3). Each mixer, equipped with a 2.4 cm diameter propeller, was appropriately positioned inside a manhole cover located on the back of the piers. An inch PVC pipe connects the manhole cover itself to the basin through a copper pipe, also one inch in diameter. Before the experimental tests, each mixer was suitably calibrated to determine at the end of the tube a current characterized by an axial component of average time speed of about 9.7 cm/s measured at a 5 cm water depth and at a distance of 10 cm from mixer. This value corresponds in the prototype to about 1.00 m/s, in agreement with project speed. Floating cork particles, suitably coloured, have been positioned in predetermined positions for the photographic visualization of the motion field induced by the agitators inside the basin. In particular, two experimental tests were conducted. The first, in which the devices with a PVC tube take water from inside of the basin and inlet it through the copper tube out of the basin itself and so the floating particles are carried by the mixers near the piers. The second in which the mixers through the copper tube inlet water from outside the basin inside it and so the floating particles are carried by the mixers outside of the basin. With regard to case 1) the tracers placed near the mixers already after 5 minutes from the start of the test are take by the mixers towards the quays and after 115 minutes still closer. The tracers positioned far from the mixers, although initially taken (a t=5') by the mixers, are trapped in the channel between the piers of basin. With regard to case 2), in Figure are plotted the trajectory of each group. It is evident that in this case, the particles already after 20 minutes from the start of the test are pushed by the mixers through the entrance, remaining here until the end of the test (t = 115'). From the comparison of the experimental tests the mixer system is effective in both cases investigated. It should also be noted that the system in the case water inlet inside the port (case 2), all the tracers positioned inside the port basin are pushed towards the entrance, a condition that does not occur in the case of water taken off towards the piers. For the particles remaining trapped in the basin, so it is necessary to install others mixers to allow to exit from the port basin.

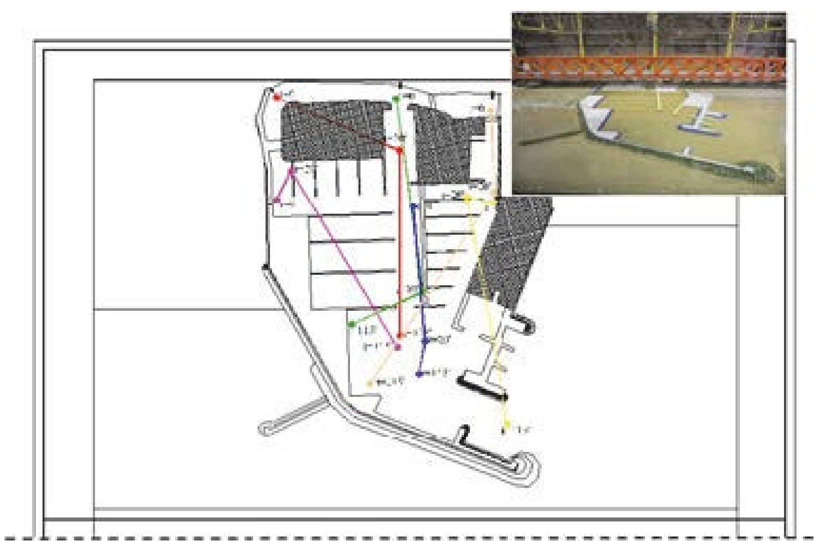

Figure 3 - Marina of Castel Volturno; Trajectory of particles – case 2).

**Port of Fiumicino**

The new tourist port of Fiumicino will be located in Isola Sacra between Capo Linaro in the north and Capo Anzio in the south [5]. The trunk section breakwaters are planned in artificial rocks (162° N - 342° N – Molo Traiano) and natural armour (180° N-0° N – Molo Claudio). The port basin has a total area of approximately 580 000 $m^2$, with an entrance of approximately 50 000 $m^2$. Inside it is planned the construction of four docks; the quays are for both fixed and floating type.

The model of the port basin has been reproduced in scale 1: 135 (Figure 4). The trunk section in model was made with limestone stone elements of suitable size; the docks have been made with steel sheet while the floating piers with cork. In the project, a forced circulation system (jet mixers) was planned with a number of mixer equal to 12 and with a flow rate of 1400 l/s for each of them. In the experimental tests, to simulate the effect of the mixers, a nozzle system was created connected to a hydraulic circuit, each with flow rate of approximately 0.008 l/s, corresponding in prototype to 1400÷1600 l/s (project value). The photographic visualization with camera of the motion field induced by the mixers was obtained by introducing floating cork coloured particles.

Figure 4 - Initial position of particles.

In particular, four of the five groups of particles have been positioned, in the initial condition, inside the docks, while the fifth near the port entrance. At the first, the arrangement and the number of the mixer were that in the project (12 mixers). It has been highlighted that this solution is not satisfactory because it determines the large areas of stagnation above all in the inner areas of the port basin. Therefore, other tests have been carried out in which the number of equipment and their position has been changed. In particular, among the experimental tests conducted, those relating to the following two conditions are reported. A first case in which 18 mixers have been used with a flow rate value of 0.008 l/s and an outlet speed of 0.40 m/s and a second case in which 24 mixers have been installed with a flow rate value and an outlet speed equal to that of the first case. Regarding case 1) all the tracers, although initially affected by the effect of the current generated by the mixers, remain trapped inside the docks and in the channel parallel to Molo Traiano. With reference to case 2), all the particles already a few minutes after the start of the test are pushed by the mixers towards the entrance, leaving definitely the basin at the end of the test (Figure 5). As for the tracers placed in the initial condition inside the central dock, these, although affected by the effect of the current generated by the mixers, remain trapped inside the dock. From the comparison of the experimental investigations carried out, it is clear that the most effective regulator system is that relating to case 2), also with the limitations of effectiveness reference to the central dock.

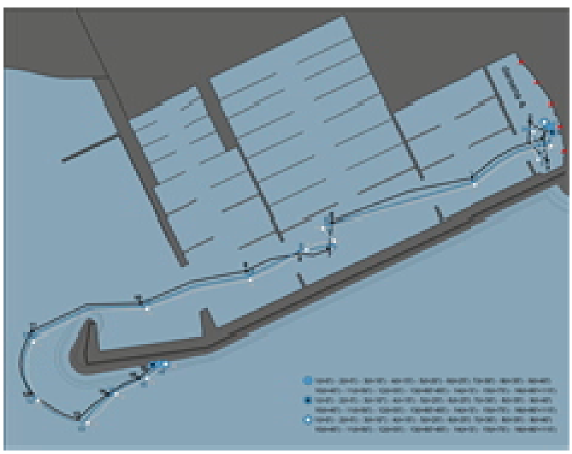

Figure 5 - Trajectory of the particles - case 2).

## Water circulation over the defence works

### Coast of Salerno

The coast of the Municipality of Salerno, about 12 km wide, is between the Municipality of Vietri sul Mare and the Picentino Torrent. To mitigate intense erosion phenomena an artificial nourishment protected by submerged breakwater spaced out with the gaps has been projected. The submerged level of the breakwater is equal to 0.50 m while the gaps have a submerged level equal to 3.00 m. The defence works are made in natural stones. The scale in a physical model is equal to 1:70 (Figure 6). The trunk section breakwater is made by limestone stone elements of appropriate size. The wave height reproduced in the model is equal to $H_s$ =0.007 m, with period $T_s$=0.5 s corresponding to a wave height in the prototype equal to $H_s$ =0.50 m, period $T_s$=3.20 s with angle propagation equal to 220° N, 230° N and 240° N. To maintain adequate water quality behind the defence works, the greatest time for water exchange, as required by the AIPCN standards, is equal to 48 h. The photographic visualization of the motion field induced by the most frequent storms within the protected basin was obtained by introducing cork-floating particles, suitably coloured, in fixed positions. Two experimental tests were made. The first in which the groups of particles have been positioned in the initial condition behind the gaps and the central breakwater in presence of $H_s$=0.007 m α=0° (220 °N), α=10° (230° N) and α=20° (240° N). The second in which the groups of particles have been positioned in the initial condition only behind the breakwaters in presence of the same wave conditions (Figure 7). In the case 2), for α=0°, the tracers positioned respectively behind second and third breakwaters exit from the protected basin after D=7 min from the start of the test and return after about 15 min and definitively move away from the protected area at the end of the test. The remaining tracers, although affected by the effect of the wave storm, stop on the shoreline after D=2 min from the start of the test. In the case of wave oblique attack, α=10°, the tracers placed behind second and fourth breakwaters move away respectively from the protected basin after D=14 min and D=18 min from the start of the test while those placed behind the central breakwater respectively after D=22 min and D=49 min. The remaining tracers initially are influenced for a long enough time by the circulation induced by the storm and then stop on shoreline. For α=20°, the tracers placed behind second and fourth breakwaters leave definitively the basin after D=17 min from the start of the test; the particles placed behind the central breakwater, although affected at the beginning of the test by the effect of the circulation induced by the storm, stop on shoreline after D=6 min. Also in case 1) an adequate water exchange of the protected basin is ensured in the presence of the most "frequent" storms. This action appears more effective as the wave angle attack increases.

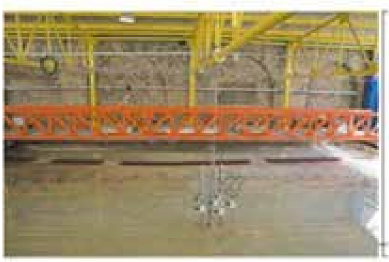

Figure 6 - Model of Salerno.

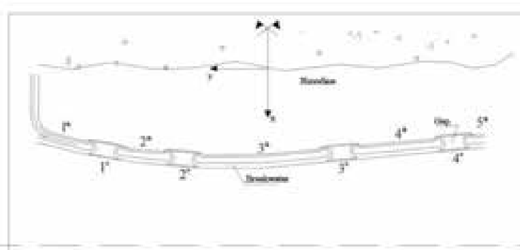

Figure 7 - Scheme of Salerno model.

**Coast of Ischitella**

The construction of a breakwater with a submerged level of 0.50 m sl has been planned protecting coastline of Ischitella. The breakwater was positioned at the depth ranging between 3.50 m sl and 4.00 m sl. The longitudinal development of the work is 890 m. There are 2 gaps wide 40 m and such as to divide the entire structure into 3 trunks, each of 270 m development; the gaps have a submerged level of -2.50 m sl and a top width equal to 24 m. As a connection the defence work to the coast, other gaps, wide 70 m, have been made at the two ends of the emerged transversal groins [4]. The behaviour of the work was studied through a 1:50 scale model (Figure 8). Only two breakwaters and two gaps and one of the two emerged transversal groin connected to the coast have been reproduced. The breakwaters have been built with limestone. The wave height reproduced in the model is equal to $H_{sm}$=0.01 m, with period $T_{pm}$=0.5 s corresponding in the prototype to a wave height equal to $H_s$=0.50 m, period $T_p$=3.11 s with angle propagation equal to 240° N and 270° N. The photographic visualization of the motion field induced by the most frequent storm within the protected basin was obtained by introducing cork-floating particles, suitably coloured, in fixed positions. Two test conditions were made in which six groups of particles, positioned in the initial condition behind the gaps (group 3 and 6) and behind the breakwaters (group 1, 2, 4 and 5), were subjected to $H_s$=0.01 m a=0° and a=30°. For a=0°, groups 1 and 2 stop on the shoreline, although affected at the test beginning by the circulation induced by the storm. The particles of group 3 and 4 go beyond the trunk section 1 and definitively leave from the protected basin after about 50 minutes; groups 5 and 6 immediately leave the basin after the start of the test (about 15 minutes). For a=30°, the tracers of group 1 and 2 partly come out from the protected basin through the groin and partly from the gap 2 (Figure 9). Group 3 over pass the trunk section 2 after about 40 minutes from the start of the test; the tracers of group 4, 5 and 6 move away from the protected basin through respectively the trunk section 2 and the gap 2, after a few minutes from the start of the test. It is evident from the comparison of the experimental investigations carried out that the circulation induced by the most frequent storms influences the protected basin. In particular, the time taken by the tracers to move away from the basin, in both cases examined, is significantly reduced if it is compared to that in the project phase. It should also be noted that the effect of the circulation induced by storms on the water exchange in the protected basin increases as the wave angle increases.

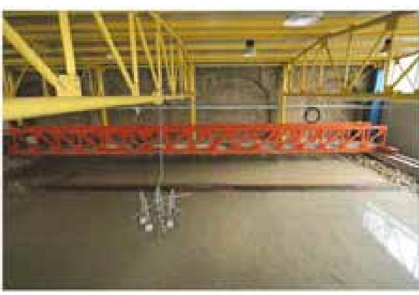

Figure 8 - Model of Ischitella.

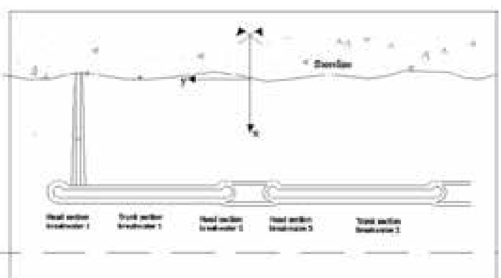

Figure 9 - Scheme of Ischitella model.

## Conclusion

The estimation of water circulation on physical model within the port basin of Manfredonia, Fiumicino and Castelvolturno and behind the defense works of Salerno and Ischitella coasts has been reported. The tests were carried out at the Maritime Hydraulics Laboratory of the University of Campania “Luigi Vanvitelli”. For the Port of Manfredonia, a forced circulation system activated by electromechanical equipment arranged inside the docks can ensure adequate water exchange within the port basin itself. This device appears more effective with jet mixers conveying the water sucked from inside towards outside of the basin. The mixers located inside of Castelvolturno port that inlet water inside the port taking it from outside, are instead more effective. The most suitable forced circulation system for Fiumicino port is that with a greater number of mixers than those provided in the project. This system allows pushing out all the tracers towards outside of basin, except for those positioned inside the central dock. As far as coastal defence works concerned, an adequate water exchange of the protected basin is ensured for both Salerno and Ischitella coasts in the presence of the most "frequent" storms. This action appears more effective as the wave angle attack increases.

## Bibliography


[1] Di Natale M., Eramo C., Vicinanza D. (2008) - *Experimental investigation on beach morphodynamics in presence of subsidence*, Journal of Coastal Research.

[2] Di Natale M., Di Ronza S., Eramo C., Vicinanza D. (2008)- *Il laboratorio di idraulica marittima della SUN: caratteristiche e potenzialità*, Atti del 31° Convegno di Idraulica e Costruzioni Idrauliche, Perugia.

[3] Di Natale M., Di Ronza S., Eramo C., Vicinanza D. (2010) - *Experimental study at port of Manfredonia (Italy)*, Atti del 32° Convegno di Idraulica e Costruzioni Idrauliche.

[4] Di Natale M., Di Ronza S., Eramo C. (2012) - *Indagine sperimentale in vasca per la verifica delle opere di difesa ambientale del Litorale Domitio*, Simposio Monitoraggio Costiero, Livorno.

[5] Di Natale M., Di Ronza S., Eramo C. (2014) - *Indagine sperimentale per la verifica del funzionamento idraulico e strutturale del porto turistico di Fiumicino (RM)*, Simposio Monitoraggio Costiero, Livorno.

[6] Frigaard P., Brorsen M. (1995) - *A time domain method for separating incident and reflected irregular waves*, Coast. Eng. 24.

[7] Kamphuis J. W. (1972) - *Scale selection for wave models*, Report no 71 of Queen's University C.E, Ontario, Canada.

[8] Kamphuis J. W. (2000) - *Introduction to Coastal Engineering and Management*, Advanced Series on Ocean Engineering, 16, World Scientific.