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WAVE INDUCED HYDRODYNAMICS FIELD AROUND A LONG SUBMERGED GROIN: THE CASE STUDY OF THE LATINA (ITALY) NUCLEAR POWER PLANT COOLING SYSTEM INTAKE

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EXTENDED ABSTRACT

Recentemente, è stato finanziato dal Ministero dell'Ambiente e della Tutela del Territorio e del Mare (MATTM) all'Università di Roma Sapienza e all'Università degli Studi dell'Aquila il progetto di ricerca MorfRESTORE, riguardante l'analisi dell'evoluzione morfologica e morfodinamica del litorale laziale compreso tra Capo d'Anzio, a nord-ovest, e il promontorio del Circeo, a sud-est; in particolar modo, si intende sviluppare un modello numerico a una linea per l'analisi dell'evoluzione morfologica a lungo termine delle spiagge sabbiose soggette a mareggiate e difese e non difese da opere costiere. Uno degli obiettivi del progetto è stato studiare l'influenza dell'impianto di raffreddamento dell'ex centrale nucleare di Latina sull'idrodinamica costiera. Il sistema è costituito da due condotte sottomarine, del diametro interno di 2.7 m, protette da una copertura in massi naturali. L'opera sottomarina, lunga circa 700.0 m, connette il torrino di presa, posizionato a largo a una profondità di circa 6.0 m, alla costa e forma un angolo di circa 25.0° rispetto alla perpendicolare alla spiaggia. Il pennello è largo circa 12.0 m ad una profondità 3.0 m rispetto al livello medio marino locale. Fino a pochi anni fa l'opera di presa era sormontata da un pontile, recentemente demolito. Essendo la profondità di chiusura della fascia attiva di circa 8.0 m (e.g., Hallermeier, 1981), la struttura può essere considerata da un punto di vista morfologico come un pennello lungo sommerso, in grado di intercettare quasi completamente il trasporto solido longitudinale. Attraverso un rilievo batimetrico multi-beam dell'area di studio è stata osservata la presenza di un canyon sottomarino lungo il fianco (lato) est del pennello. Inoltre, le tipiche zone di accrescimento sovraflutto e di erosione sottoflutto, indotte dai pennelli emersi, non sono state osservate nell'intorno della struttura. L'obiettivo di questo lavoro è quindi quello di studiare il campo idrodinamico indotto dalle onde frangenti nell'intorno dell'opera sommersa per indagare l'origine morfodinamica del canyon sottomarino osservato. Infatti, l'influenza dei pennelli sull'idrodinamica costiera include fenomeni di rifrazione e frangimento delle onde e circolazione nella zona di surf, che inducono la formazione di correnti di rip in prossimità di essi. Correnti di rip molto forti agiscono sul trasporto solido in sospensione vicino al pennello e possono causare la perdita di sedimenti verso il largo e favorire conseguentemente uno scavo sottoflutto. Utilizzando il modello numerico XBeach (e.g., Roelvink *et alii*, 2010), sono state eseguite simulazioni numeriche bidimensionali del campo di flusso nell'intorno del pennello. Si è utilizzato XBeach in quanto è stato sviluppato appositamente per simulare i processi idrodinamici e morfodinamici costieri. Il modello risolve equazioni 2DH per la propagazione delle onde, il flusso, il trasporto solido e le variazioni del fondale. Sono state effettuate simulazioni con differenti valori di altezza d'onda significativa H_s e direzione media di propagazione θ, con lo scopo di identificare i parametri ondametrici che possono giustificare l'evoluzione del fondale osservata nell'area in cui ricade l'opera. Le informazioni riguardanti il clima medio marino sono state ricavate dall'analisi della serie storica ondametrica in re-analisi del gruppo MeteOcean del DICCA dell'Università di Genova, che si estende da gennaio 1979 a dicembre 2017 (e.g., Mentaschi *et alii*, 2015). Le simulazioni numeriche, condotte su una batimetria ideale sulla quale è stato posizionato un pennello sommerso, hanno confermato la presenza di una corrente di rip sul fianco est della struttura e la conseguente perdita di sedimenti verso il largo. Inoltre, lo studio ha dimostrato che la circolazione costiera nella regione di studio dipende principalmente dall'angolo di incidenza delle onde e che solamente per un intervallo limitato di valori di quest'ultimo si generano correnti di rip.

ABSTRACT

This study aims to reproduce the hydrodynamics (waves, currents and sediment transport) in the area surrounding the submerged cooling system of the Latina nuclear power plant (Latium region, Italy) in order to investigate the morphodynamic origin of the observed submarine channel. The bathymetry survey of the area revealed the presence of a rip canyon on the east flank of the structure. This structure is made up of two submerged pipelines, 700 m long, covered by a submerged rubble mound and extends to the -6 m isobath. From a morphological point of view, it could be considered as a "long submerged groin", being the local closure depth of about 8 m. The XBeach numerical model was applied to an idealized bathymetry with a submerged groin in order to confirm the formation of a rip current on the east flank of the structure, which causes loss of sediment seaward. Numerical simulations reveal that the nearshore circulation mainly depends on the incident wave angle and also demonstrate that the rip current occurs for a limited range of mean wave directions.

KEYWORDS: groin, nearshore circulation, rip current, sediment transport, XBeach.

INTRODUCTION

The research project MorfRESTORE deals with the morphological and morphodynamic evolution of the littoral stretch between Capo d'Anzio, to the north west, and Capo Circeo, to the south east (Italy-Latium Region). It has been recently funded by the Italian Ministry of Environment and Protection of the Territory and the Sea. The whole study aims at developing an innovative numerical one-line model for the analysis of the long-term morphological evolution of sandy beaches subjected to storms, defended and not defended by coastal structures.

Along the analysed stretch, the intake pipeline for the cooling of the Latina nuclear power plant is of interest. Figure 1 shows the area map under study and the geographic location of the cooling system.

Fig. 1 - The area map under study.

Figure 2 shows the plan view and the cross-section of the system which is made of two submerged pipelines (inner diameter of 2.7 m) protected by a submerged rubble mound. The structure, about 700 m long, connects the water intake, located offshore at a water depth of about 6.0 m, to the shore. The rubble mound berm is about 12.0 m wide with a freeboard of 3.0 m, with respect to the local mean sea level (m.s.l.). An emerged pier was present along the submerged rubble mound (for maintenance purposes), now dismantled. Being the local closure depth of about 8.0 m (e.g. HALLERMEIER, 1981), the submerged rubble mound may be considered from a morphological point of view as a "long submerged groin", i.e. it is capable to stop the total amount of the longshore sediment transport (i.e. TARRAGONI *et alii*, 2014).

With reference to Fig. 3, which is a very accurate multi-beam bathymetric survey carried out in the area where the structure is located, it can be noted the presence of a submarine canyon, probably induced by a seaward current, forced by the waves breaking on the submerged groin. Rip currents are narrow, seaward currents which develop when longshore gradient of the breaking waves induced circulation occurs. As an example, they occur when obliquely incident waves induce an alongshore current that can be deviates seaward by a coastal structure.

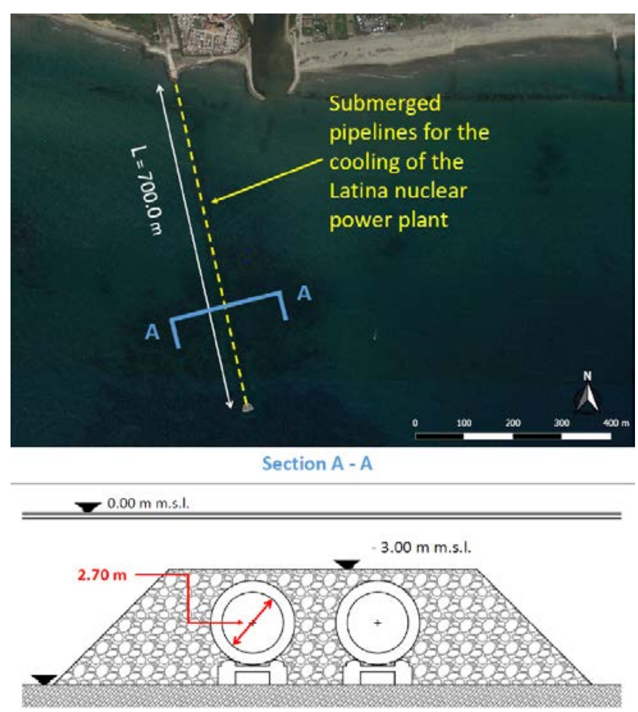

Fig. 2 - Upper panel: the plan view of the cooling system. Lower panel: the cross-section of the cooling system.

Indeed, updrift current occurs when a structure acts like a dam to the wave-induced flow and deflects the longshore current offshore. Furthermore, rip currents occur when breaking waves produce a long-shore gradient in the m.s.l. and a consequent circular flow pattern (eddy) at the downdrift side of the structure. This eddy gives an additional seaward current.

In order to gain insight on the observed morphological changes of the seabed induced by the presence of the structure, a numerical study was carried out. The aim of the study is to reproduce the hydrodynamics (waves, currents and sediment transport) in the area surrounding the groin in order to investigate the morphodynamic origin of the channel under observation.

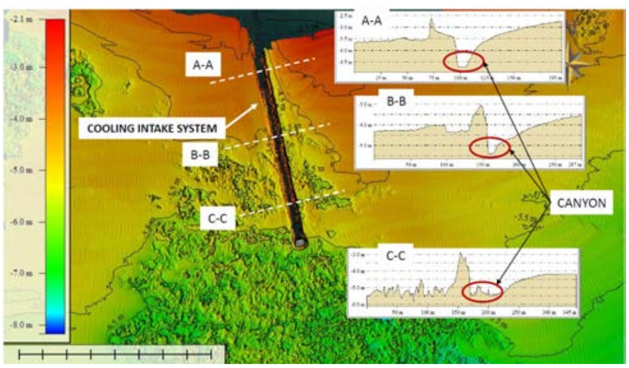

Fig. 3 - Multibeam bathymetric survey around the cooling system.

DATA COLLECTION

Wave data (significant wave height H_s, peak wave period T_p and mean wave direction θ) were inferred from Dicca MeteOcean wave hindcast dataset, spanning from January 1979 till to December 2017 (e.g., Mentaschi *et alii*, 2015) 23 km north - west of the area of interest (41°20'23.98"N, 12°33'35.98"E) in a water depth of 124.0 m (Fig. 4. Left panel). Deep water wave parameters were propagated shallow water (Fig. 4. Right panel), applying the Inverse spectral refraction Merope model, in order to retrieve significant wave height, peak wave period and mean wave direction in the vicinity of the groin at a water depth of 15 m.

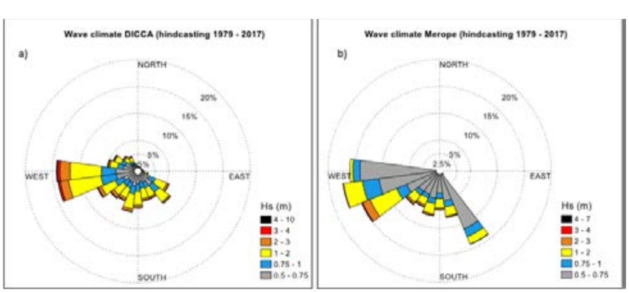

Fig. 4 - Left panel: wave climate offshore. Right panel: wave climate propagated at a water depth of 15 m.

Merope is a spectral inverse refraction Lagrangian model, based on the method introduced by Abernety & Gilbert (1978), which allows the propagation of the historical hindcasting series from offshore to nearshore. In order to evaluate the changes undergone by the wave motion during propagation, only the shoaling and refraction phenomena have been considered (neglecting the bottom friction).

Seabed sediment grain size (i.e. D_{50}, the grain diameter that 50% of a sediment sample is smaller than) were obtained from soil sample of the study area taken from Latium Region soil campaign in 2009. The grading curve of the soil sample is shown in Fig. 5.

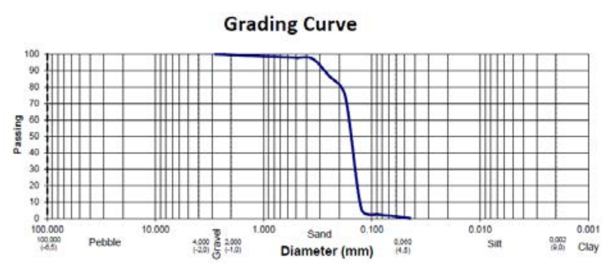

Fig. 5 - Grading curve at a water depth of 5 m.

NUMERICAL SIMULATION

The open source XBeach numerical model (e.g. Roelvink *et alii*, 2010) was used to compute the flow characteristics around the groin region. XBeach is a two-dimensional model for wave propagation, long waves and mean flow, sediment transport and morphological changes of the nearshore area. In the present study, the model was used in two distinct steps:

• numerical simulations aimed at verifying the presence of a rip current at the east flank of the submerged groin were performed;

• numerical simulations aimed at identifying sea states inducing sediment transport and the resulting loss of material seaward were performed.

The model bathymetry was inferred from the real bathymetric configuration of the site. Then an alongshore uniform bathymetry was implemented, with a slope of 1:150. A constant - depth zone was added offshore to the domain for numerical stability purposes (Fig. 6). Groin was reproduced by specifying an impermeable structure at the required cross- and long-shore locations. Groin length, thickness and elevation were selected in order to replicate the observed case. The groin is 25° rotated with respect to the shoreline-perpendicular.

The model domain extended 4860 m in cross-shore direction and 4080 m in long-shore direction.

The angle between the *y*-axis of the computational domain and the true north is equal to 115°. In the followings, north, south, west and east are used with reference to the computational

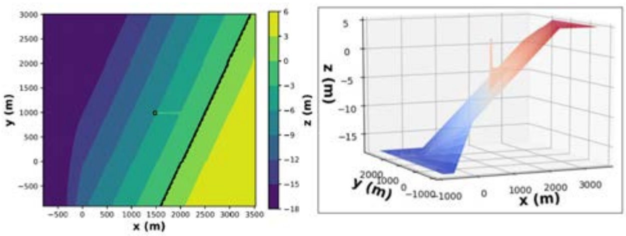

Fig. 6 - Left panel: plan-view of the model bathymetry. Right panel: 3D representation of the domain bathymetry.

domain. At the north and south boundaries (with reference to Fig. 6) wall conditions were imposed, based on the results of a sensitivity analysis. At both west and east boundaries of the domain, absorbing boundary conditions were applied.

Two different computational grids have been employed for simulations. The first one was used in order to investigate the presence of the rip current on the east flank of the groin and presents a constant grid step $\Delta x = \Delta y = 20$ m. The second one was used to estimate the cross-shore sediment transport. It presents a gradual variability along both horizontal and vertical directions, with a grid step ranging between 5 m in the region around the structure and about 90 m offshore. This made it possible to obtain more detailed results in the areas of greatest interest and to speed up the calculation of the simulations in other areas, where such detail is not considered required. The wave directional resolution was 5°.

All model simulations were performed using representative wave climates and neglecting the influence of tide and wind. The simulated incident wave conditions for initial runs correspond to regular waves, whose characteristics are listed in Table 1. In particular the wave height H_s and the wave period T_p ($T_p = \alpha H_s^{\beta}$, with $\alpha = 4$ and $\beta = 0.5$) are constant, while the wave direction θ varies between 250° and 300° (incoming direction measured clockwise with respect the y-axis of the computational domain).

In order to gain insight on the influence of rip current on the suspended sediment transport, further simulations have been performed. For each wave directions $\theta = 285°$, $\theta = 290°$, $\theta = 295°$, six different incident significant wave heights were selected, based on the wave climate in the vicinity of the structure at a water depth of 15 m: $H_s = 2.0$ m, $H_s = 3.5$ m, $H_s = 4.0$ m, $H_s = 4.5$ m, $H_s = 5.0$ m and $H_s = 5.5$ m (maximum significant wave height measured from wave directions of interest, based on the wave data propagated by Merope model).

WaveState	*H_s (m)*	*T_p (s)*	*θ (°)*
WS1	*2.0*	*5.66*	*250*
WS2	*2.0*	*5.66*	*260*
WS3	*2.0*	*5.66*	*270*
WS4	*2.0*	*5.66*	*280*
WS5	*2.0*	*5.66*	*285*
WS6	*2.0*	*5.66*	*290*
WS7	*2.0*	*5.66*	*295*
WS8	*2.0*	*5.66*	*300*

Tab. 1 - Tested regular waves – STEP 1.

WaveState	*H_s (m)*	*T_p (s)*	*θ (°)*
WS1	*2.0*	*7.87*	*285*
WS2	*3.5*	*9.73*	*285*
WS3	*4.0*	*10.24*	*285*
WS4	*4.5*	*10.71*	*285*
WS5	*5.0*	*11.15*	*285*
WS6	*5.5*	*11.56*	*285*
WS7	*2.0*	*7.87*	*290*
WS8	*3.5*	*9.73*	*290*
WS9	*4.0*	*10.24*	*290*
WS10	*4.5*	*10.71*	*290*
WS11	*5.0*	*11.15*	*290*
WS12	*5.5*	*11.56*	*290*
WS13	*2.0*	*7.87*	*295*
WS14	*3.5*	*9.73*	*295*
WS15	*4.0*	*10.24*	*295*
WS16	*4.5*	*10.71*	*295*
WS17	*5.0*	*11.15*	*295*
WS18	*5.5*	*11.56*	*295*

Tab. 2 - Tested regular waves – STEP 2.

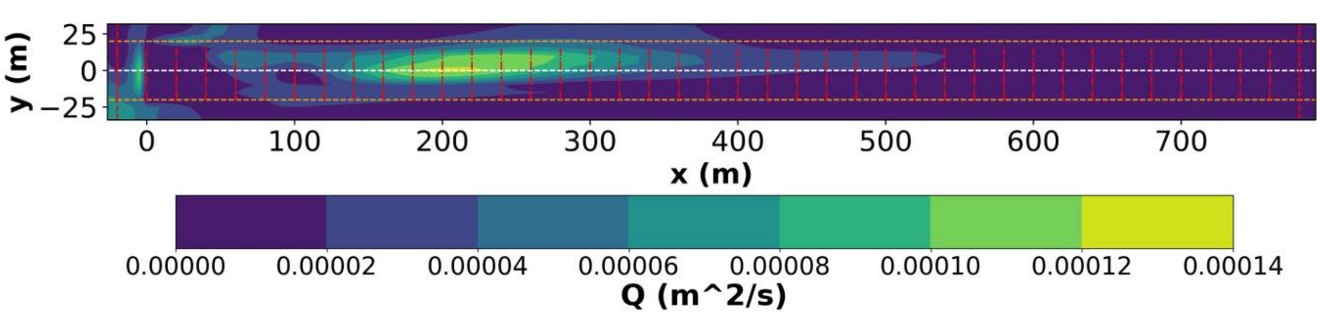

Fig. 7 - Cross sections all along the submerged groin.

The reproduced sediment is characterized by D_{50} = 0.16 mm, selected based on the sieving curve of the sediment samples collected in the area close to the groin. In order to identify the wave parameters that induce loss of sediment offshore, a series of cross sections (see Fig. 7) was defined and the cross-shore sediment transport was calculated. Hence, the sediment transport that occurs on both sides of the groin has been characterized**.**

RESULTS AND DISCUSSION

Simulations showed that the waves which induce rip current on the east flank of the groin come from a narrow sector spanning from 285° and 295°.

Figure 8 shows the propagation of the incoming waves. Waves break at the (submerged) groin location. The colour map in Fig. 9 shows the water elevation (with respect to the mean sea level) distribution in the area of interest. The vector plot of the wave induced hydrodynamic field, in Fig. 10, shows the dominant circulation pattern around the groin. For all the figures only a small portion of the full domain is represented in order to magnify the area of interest around the groin.

It should be noted that no distinction is initially made between the cliff face and the shore profile; this boundary emerges through model iteration. The highest element is therefore typically set to be a small height above the expected cliff toe.

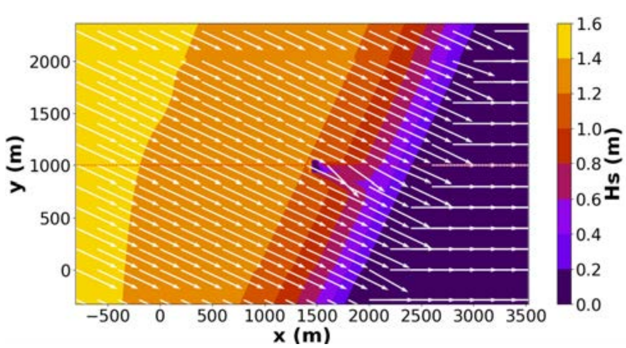

Fig. 8 - Vector plot of the wave height H_s for θ = 295° with reference to the first grid configuration.

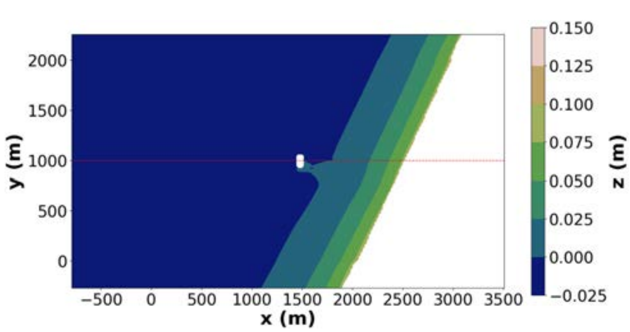

Fig. 9 - Map colour of the water level for θ = 295° with reference to the first grid configuration.

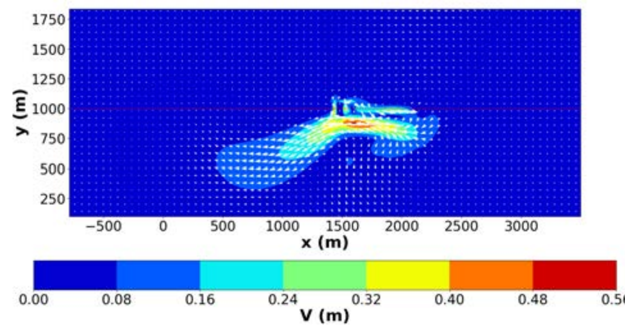

Fig. 10 - Vector plot of the velocities around the groin for θ = 295° with reference to the first grid configuration.

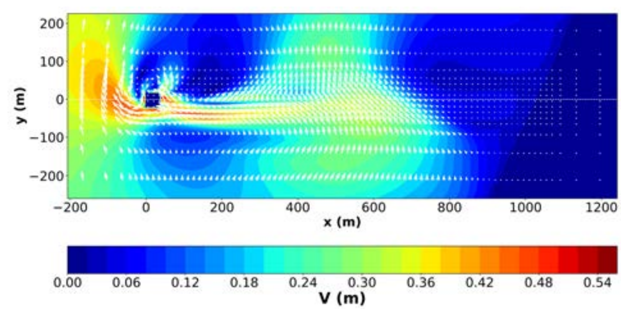

Fig. 11 - Vector plot of the velocities around the groin for θ = 295° with reference to the second grid configuration.

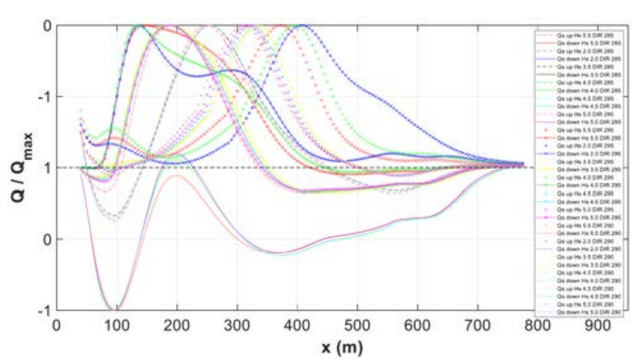

Fig. 12 - Non-dimensional cross-shore sediment transport.

Figure 11 shows the circulation pattern around the groin if the mesh resolution is increased from a discretization step of 20 m to 5 m.

Figure 12 shows the results of the second step of the study. The *x*-axis represents the sections locations from offshore to the shore, with the origin located at the offshore tip of the groin; on the y-axis the normalized cross-shore sediment transport is represented. Positive values indicate landward directed sediment transport, while negative values identify seaward directed sediment transport. Each coloured line stands for a different wave state and for each side of the groin ("up" stands for the northen side, "down" for the southern side).

Looking at Fig. 12, it can be concluded that only for the direction θ = 285° N the rip current induces sediment transport directed offshore and, therefore, possible excavation on the Southern side of the groin. Moving to the global refence system, it can be observed that the rip currents on the southern side of the groin occur for waves coming from a narrow angular sector, ranging between 170° N - 180° N.

CONCLUDING REMARKS AND FUTURE IMPROVEMENTS

This work aims to illustrate the results of the hydrodynamic study of the area around the long submerged groin deployed to protect the intake pipelines of the Latina nuclear power plant cooling system. The aim is to identify the wave conditions for which rip currents occur on the east flank of the structure and may causes loss of sediment offshore. Hydrodynamic characteristics are of great importance for the evaluation of sediment transport patterns and, hence, for the morphodynamics characterization. The main conclusion of the present work is that the wave direction mostly influences the nearshore circulation.

Moreover, from the study conducted it has been concluded that only for sea states characterized by a wave direction θ = 170° N, the generated rip current produces loss of sediment offshore with consequent formation of an excavation to the east of the groin. The influence of several groin configurations (e.g. by modifying its length, the freeboard, the berm width) on the hydrodynamics and morphodynamics is under investigation. Real bathymetry around the groin will be reproduced to estimate the mean annual sediment loss due to the groin influence

ACKNOWLEDGEMENTS

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