The effect of wave parameters on the current patterns and sediment transport in the Inlets

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Abstract: Hydrodynamic factors such as waves and currents play significant role in the inlets morphology changes. Therefore, recognizing their roles, as the transference processes, plays an effective role in detecting the geometry, as well as, the forms of shores and inlets. Wave is a hydrodynamic factor and wave break in shallow water of inlet portal causes the transfer of some shore currents and sediment to this zone. This research focuses on, the performance of relevant parameters such as, wave height, direction, wave period and its effect on the sedimentation pattern, and erosion in the inlet. For this purpose, a basin is simulated with irregular meshing and the dimension of 10 to 50 m using the Mike software. Regarding the height effect, first, the waves are reflected by various heights and constant period as cross- shore. Then, for studying the role of wave ray angle the waves sent to the inlet with constant height and period under various angles. Finally, to investigate the effect of wave period, the wave appears to be reflected to the inlet with constant height under various periods as cross-shore. The results obtained from the simulation show that the change of wave height has a significant effect on the current pattern and sedimentation. The speed of current as well as the volume of transfer sedimentation in the channel increase with increasing in the wave height. In addition, by changing the wave reflection angle against shore line, the current pattern and sedimentation are changed in the inlet and its sides. However, the period of wave has no significant effect on the pattern and current rate and sedimentation.

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1. Introduction

Inlets play an important role in marine transportation, as the connection between free water and channels and gulfs of which a wide, deep and permanent channel is of great importance. These marine channels are complex due to various factors of hydrodynamic and sedimentation. Ebb and flood, from one hand, and the energy of the waves, on the other hand create an active sedimentation environment in the inlet. Therefore, inlets play significant role in controlling the sediment movement of and its distribution in the local and regional areas. Hydrodynamic parameters of inlets such as waves and marine currents are important factors in determining the geometry and form of shore in the inlet. Seasonal changes of waves

And marine currents and their permanent interference in the inlets have significant effect on the morphology of inlets. Sediment accumulation in the portal and channel of inlets, causes shallowness and difficulties in the floats passage, and should be periodically removed. Exact recognition of alluvial process in the inlets not only helps their optimum use but also reduces the cost of their maintenance as well as that of protective projects. Several researchers have studied the hydrodynamic behavior of inlets and some of which are referred in the following.

Leeuwen et al. (2002) studied a rectangle basin connected to the ocean through a shallow inlet using a physical model. They investigated the effect of Coriolis force in two statues: cross shore current and long shore current. (Leeuwen et. al., 2002). A result of this study is the formation of vortex currents in two sides of mouth of the inlet that is due to the tide and ebb currents and their frictions with the walls of two sides of inlets. He concluded that Coriolis force has no significant effect on the vortices from.

Militello et al. Modeled an ideal inlet with 5 m depth. The pond's dimensions were 5km×1.5km. The dimensions of inlet and gulf as well as the assumed channel were almost as those of Shinnecock inlet in New York. This study showed that the waves flow caused sedimentation in the jetties up drift. The breaking down of waves on the ebb delta will cause its erosion. The morphology of inlet and up drift sides of ebb delta are changed by changing the direction of ebb currents. Therefore, wave, ebb and tide current and sedimentation transfer, all together, make an ideal inlet (Militello et al., 2003).

In another research, Karami Khaniki et al. (2011) studied the current model and sedimentation due to cross-current in the inlet portal. For this purpose, they simulated a shore basin, connected to the open sea, in Mike 21 software. They applied an unstructured flexible mesh with the dimensions of 10 to 50 m in a finite difference model with 1 s time step. In this simulation, the wave with 1.5m height and 8 s period was of as cross shore current and the current velocity and sediment transfer are calculated in various parts of inlet. The results of simulation showed the current field in the portal as four vortices in the up drift and down drift of the inlet. These vortex currents cause corrosion and sedimentation in different parts of inlet.

Fachin et al. (2002) investigated the effects of wave angle, height, undertow current load location and wave energy on the shore. The results showed that the bed changes depend severely on the wave angle. The cross-shore currents produce reverse loads and the waves that are directed obliquely conduct the shore currents to the coast and cause partial changes in the form of bed.

The above vortices are observed by Kennedy in two sides of return current as well (Kennedy, 2003). He believed that the high velocity of return current in the portal of return channel was due to a pair of strong vortex existed in the two sides of portal.

Plecha et al. (2011) studied the effect of wave on inlet morphology through numerical simulation. They analyzed the bed changes, sediment flow and bed changes rhythm for 8 waves in the bed. According to the obtained results the effect of simulated waves is shown only in the inlet and near shore. The bed changes and sediment transfer depend on the wave height rather than the wave frequency. These results can be achieved by analysis of each wave separately as well.

2. Materials and methods:

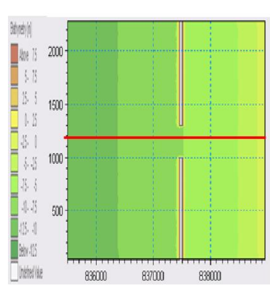
The used model

To achieve the purposes of the study, Mike 21 modeling software is used which has been established and improved by Danish Hydraulic Institute in cooperation with Water Quality Institute. This software has high calculative and graphical capabilities in modeling shore complex processes in shallow regions, gulfs and seas.

The module used in this study is Coupled Mike 21/3 of software box that is a dynamic modeling system for shore applications in the estuaries and river area and inlet. Couple Model FM sub sets – including hydrodynamic module or hydrodynamic (HD), sand transport (ST) and spectral wave (SW) are used for modeling sediment transfer the wave which is the main module based on calculation components. Hydrodynamic (HD) concludes ebb and flood, river, wind, currents due to wave, storm transposition and tidal currents. The changes in water level as well as currents can be studied by this module. It should be mentioned that this modules can simulate the currents in a one- layer liquid. The currents are of tidal and those due to the wave or a composition of both. In this study, 2-D model of current is used in HD module based on shallow water equations and momentum in which the averaged equations of Navier Stock are integrated in a non-compacted form. ST model is used to investigate the transfer of non-cohesive sediments under the effect of flow and wave. This model is used to calculate the changes of non-cohesive ST under the effects of wave and current. Wave module or SW can simulate growth rate, reduction and transfer of waves from far or near distance of the shore, Dura waves concerning shallowness, reflection and differentiation.

Design and implementation of the model basin:

Here, the effects of height, period and wave reflection are studied on the pattern of the current due to wave and their influences on the sedimentation and erosion in the inlet. In this regard, a basin with 3500 m length, 2200 m width 0.0023 bed gradients and 300 m inlet width are used. The dimensions of bed are shown in Fig.1 and its topography and mesh, to be used in the numerical simulation, in Fig 2. The mesh of basin is irregular with the triangular element of the dimension of 100m in the basin and 25m in the channel. The time step and total time for performing the model are 1s and 12 h, respectably. The sediment is non-cohesive with the diameter of 0.2mm.



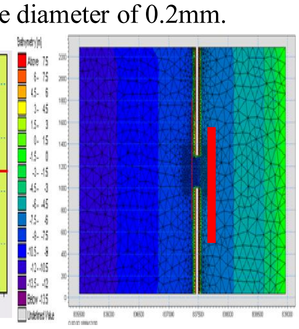


Fig1: The studied inlet (section 1) Fig 2: mesh Model (section 2)

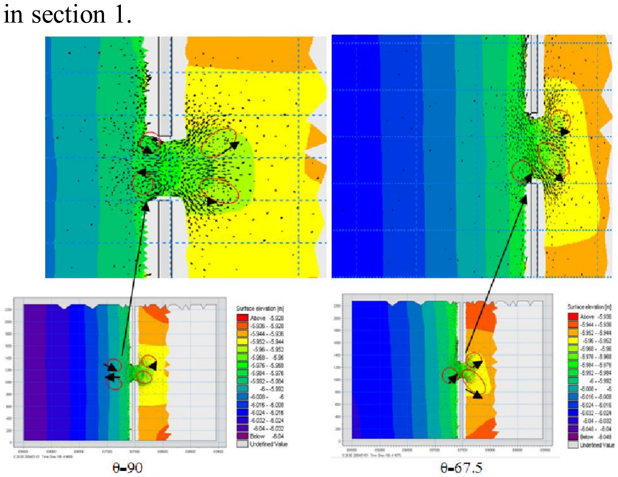
The effects of wave parameters, height, direction and period have been studied on the flow models and sedimentation in inlet in, 3 stages. Regarding the height, first, the wave is reflected as cross-shore current with various heights and constant period. Then, the direction effect of the wave is above mentioned evaluated it in various directions. Finally, the wave with is reflected as cross-shore to investigate the effect of wave period on the flow model and sedimentation. The variables are shown in the below table (table1).

Table 1: The properties of the wave entering to the inlet

angle of wave (degree)	Wave period (s)	Wave height (m)
90	8	0.75
90	8	1.5
90	8	2.2
0	8	2.2
22.5	8	2.2
45	8	2.2
67.5	8	2.2
90	8	2.2
90	6	2.2
90	8	2.2
90	10	2.2

3. The results of simulations

Fig.3 shows the velocity distribution of the flow due to the angle change of the wave with 2.2m height and Fig. 4 shows the distribution of resulted bed changes. Fig. 5 shows the speed components due to the changing of wave reflection angle along the section 1 and Fig 6 shows the in section 2. Figs. 7 show Bed level change due to changing the wave angle in section 1, 2. Figs. 8 show Velocity changes of wave current and bed level changes with various heights in section 1. Fig.10. A show the distribution of bed changes and Fig.10. B show time series of the changes rate of the flow velocity for various periods in section 1.



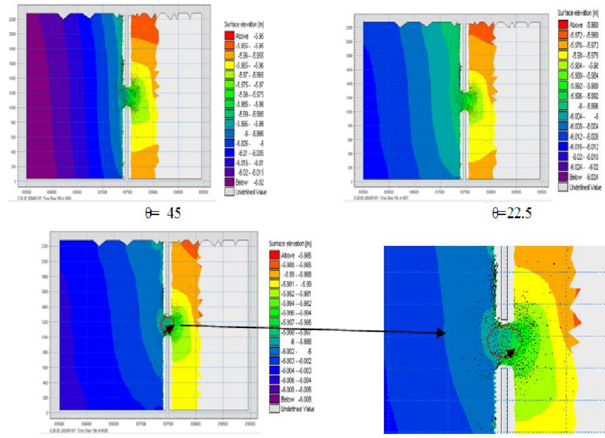


Fig. 3: The changes of water level distribution with velocity vectors cross shore under various wave ray angles

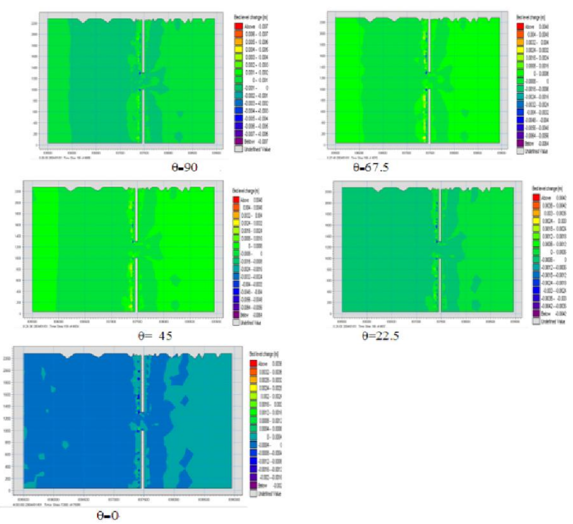


Fig. 4: The rate of bed changes under various reflection angles

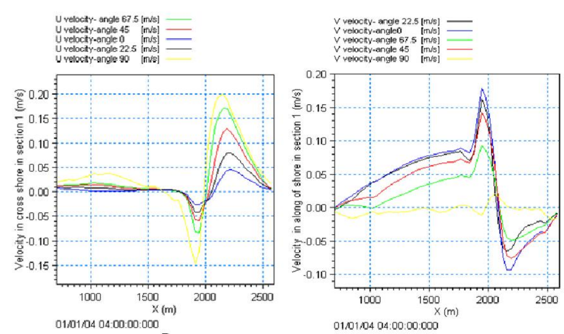


Fig. 5: The velocity components due to changing the wave reflection angle along section 1 A. Velocity components in long shore and B. Velocity component in cross shore current

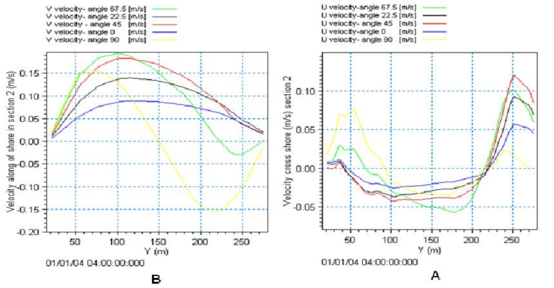


Fig. 6: Velocity change due to changing the wave angle in section 2

A. Cross shore current and B. Long shore current

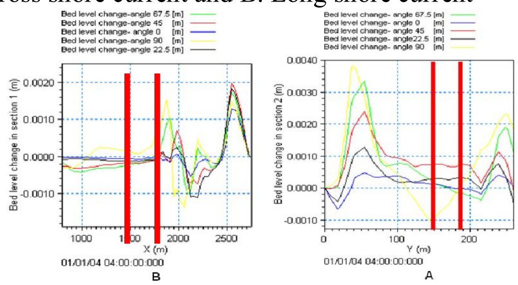


Fig. 7: Bed level change due to changing the wave angle (channel is shown in red lines)

A. Bed level changes in section 2 B. Bed level changes in section 1

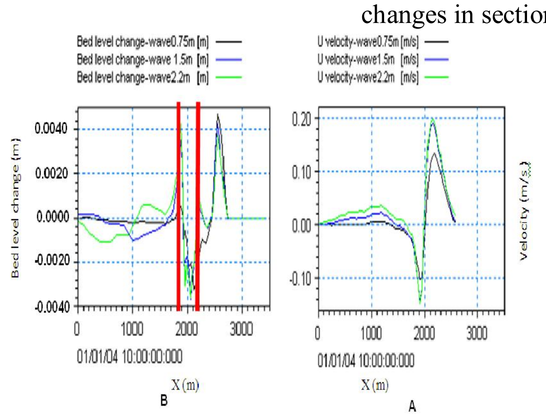


Fig. 8: Velocity changes of wave current and bed level changes with various heights in section 1 (Channel is shown in red lines)

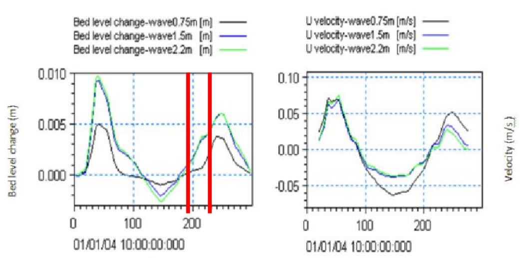


Fig. 9: Velocity changes of wave current and bed level changes with various heights in section 2 (Channel is shown in red lines)

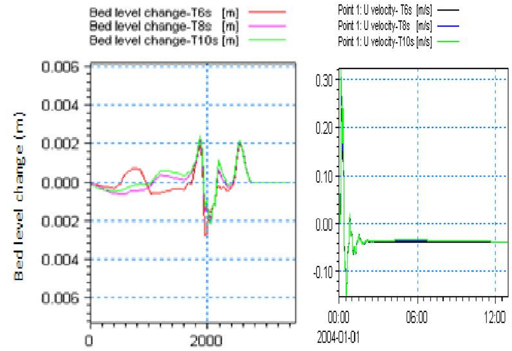


Fig.10. A: The distribution of bed level changes for various periods Fig.10.B: Time series of the changes rate of the flow velocity in section 1

Calibration:

Fig.11 shows the changes H_0/L_0, a symbol of dimension less height of the wave flow to the parameter without H0/WT. In this figure, the results of the model (Fig. 11 A) are compared with those of field studies (Fig. B).

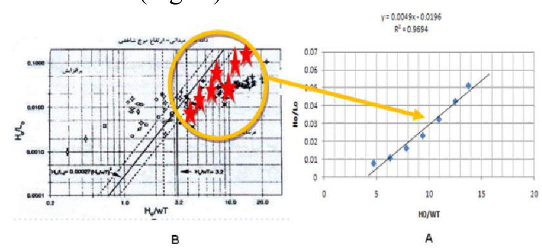


Fig. 11: A. Pre- erosion searcher in the channel by using the results obtained by the model B. Pre- searchers of erosion and accretion using field data (Kraus, 1992).

Fig. 11: B shows the results of field investigation. The assumed plotted lines; attributing 10% transformability in the wave height is depth index (Hs) wave current period index (T_s) and grains settlement velocity (w_s) (H_0,T and w in the figure).

First, the following simple predictions are proposed:

$\frac{H_{0,s}}{W_s T_s} < 3.2$ (Accrétion)

$\frac{H_{0,s}}{W_s T_s} \geq 3.2$ (Erosion)

Then, the diagonal line was replaced by this criterion in Fig 11.

The points shown in Fig. 11 A are obtained based on regression coefficient of 0.96 which have proper consistency with the field studies (Kraus, 1992). They indicate the reciprocal relationship between channel erosion and the reflection wave height, and good fitness with the field data in Fig. 11 B.

4. Discussion and conclusion

A. The effect of wave attack angle

According to Fig.3 the wave moves as cross shore current towards channel. As the water is swallowed, the wave is broken and enters the portal with high velocity. The direction of wave is changed when it exits from the portal. The velocity component is dominated in the cross direction and causes two vertices in two sides of the channel. Also the torsion radius of the vortices and therefore the flow velocity in the shore side is higher than sea side (Fig. 4B). Sedimentation model acts according to flow model. As is shown in figure 9 A, the current takes out the sediments from the mouth during the breaking of wave, and accumulates them in two sides of the portal. Then they are vertically conducted toward sea and inside the basin by vortices to from tidal and ebb deltas. By shifting the reflection angle of the wave toward inlet portal, the current velocity is divided into two components: cross shore current (U) and long shore current (V).

According to Fig. 5 A, B. by reducing reflection angle to 67.5, the side flow becomes stronger and flow to the mouth increases. This will result in the reducing the velocity, weakening the sea vortices and strengthening the shore vortcies. According to the sedimentation model, the ebb delta is stronger than tidal delta. If wave angle is 45 degree, the velocity and shore current will increase which takes more water and sediment to the shore. In this case, the length of erosion and the height of ebb delta have their maximum values (CEM- part 3-chapter 2). By reducing the reflection angle to 22.5, sea vortices and shore current will have the same direction the sedimentation model acts as current model. If the reflection angle is zero, shore current plays an effective role in water transport, sedimentation and ebb delta forming. Strong by passing currents are formed in front of it and a single vortical current in the east of the inlet. The sedimentations are formed in the sea side. However, in section 2 by increasing the angle, the velocity and shore current (cross current component) increase and the sediments are formed in the down drift (Figs. 12, 13).

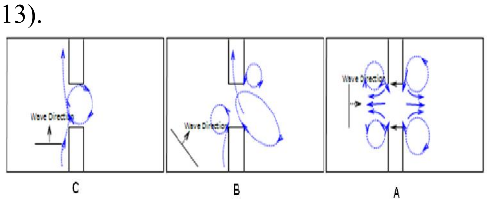


Fig. 12: The effect of wave direction on the current model in the inlet

A. Cross shore current; B. the wave with 45 degree angle to the shore line; C. long shore current

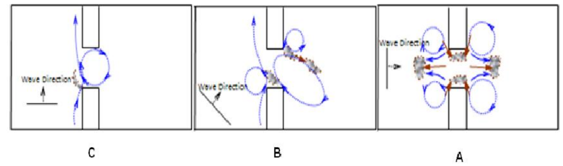


Fig. 13: The effect of wave direction on the sedimentation model in inlet
A. Cross shore current; B. Wave with 45 degree angle to the shore line; C. Long shore current

The effect of wave height

The simulation results showed the current pattern in the mouth under the effect of cross shore current in the form of four vortices in the up drift and down drift of the inlet. These vertical currents cause erosion and sedimentation in various parts of inlet and its model is shown in Fig.3.A.

According to this figures, increase of the height has no effect on current pattern. However the velocity and radius of vortex increase by increasing the wave length and the breakdown point of the wave is shifted toward the channel portal (sea side). Also, the vortices penetrate further into the mouth inside their radii. However the vertical velocity towards the sea is less than that of the shore. In other words, while shore eddy vortices become stronger, the main sea vortices are weakened and move towards the shore.

The sedimentation performance of the inlet is similar to Fig 4A. Based on this figure, the vortices formed in four corners of the inlet cause transportation of water and sediment from four sides to the portal center. The sediments are settled in the center of the portal due to the low velocity of flow there, resulting in swallowing. It should be mentioned that current are towards the sea and inside the basin as cross-current after settling the sediments in the portal. The wave breakdown causes the shallowness in the portal and the sediments transported by the vortices are delivered towards the two sides of the inlet channel creating ebb and tidal deltas. In addition, sedimentation is formed in the latitudinal sides of the channel. By increasing the wave height, the sedimentation and erosion height are increased in both longitudinal and latitudinal sections. The changing in the wave height will cause the change of current pattern in vertical cells of the region near the shore.

The effect of wave height change on the erosion and sedimentation in the longitudinal section of channel (in section 1) is shown in Fig. 14. According to this figure, by increasing in the wave height, the heights of up drift and down drift deltas of the inlet increase and their peaks proceeds toward deep water. However, the hole created in the center of portal becomes deeper and it tends towards the deep water. It should be mentioned that the velocity of inflow is higher than that of outflow. This shows that the volume up drift delta is more than that of down drift (Fig. 14).

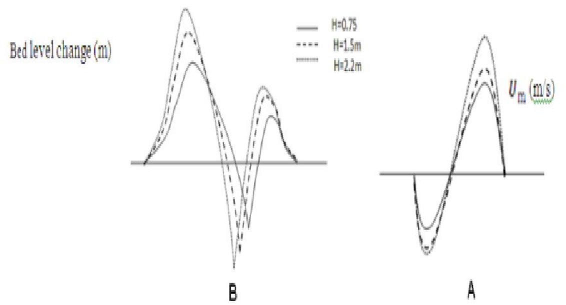


Fig. 14: The effect of wave height on current model and sedimentation

A. Velocity changes of wave flow. B. The changes of bed for the wave with various heights

The relationship are obtained between sediment problems wave properties (Period and height) by numerical modeling results and shown in Table 2.

Table 2: Length, width and height equations of sedimentation and erosion before and after the mouth obtained through simulation results

equations	before of the mouth	In the mouth	after of the mouth
Eq. Length	$L_1 = 6.4881 H_W^{0.656} T$	$L_2 = 1.01 H_W^{-0.193} T_W^{0.61}$	$L_3 = 14.31 H_W^{0.51}$
Eq. Width	$Y_1 = 6.488 H_W^{0.656} T_W$	$Y_2 = 5.186 H_W^{-0.384} T_W^{1.1}$	$= 14.012 H_W^{0.605} T_W^{0.}$ Y_3
Eq. Height	$51 H_W^{0.267} T_W^{0.103}$ $D_1 =$	$D_2 = 0.251 H_W^{0.872} T_W^{-0.}$	$.108 H_W^{0.294} T_W^{0.294}$ D_3

Where, L_1, Y_1, D_1 are the length, width and height of sedimentation, respectively, before the portal; L_2, Y_2, D_2 are length, width and erosion, respectively, in the mouth; L_3, Y_3, D_3 sedimentation height after the portal in m; Hw is wave length in m; and T_w is wave period in seconds. According to these equations by attacking long waves to mouth, the vortex velocity increases. Moreover by improving the vortexes, the sedimentation volume increases in the up drift and down drift of the channel. The erosion also increases inside the channel causing the improvement of shallowness in inlet, namely in up drift.

C. The effect of wave period

According to Fig. 10, changing in wave period has no significant effect on the, current pattern and sedimentation. Although the velocity and bed level increase.

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References:

1- DHI, (2007), Mike21's User Manual; Danish Hydraulics Institute, Denmark.
2- Fachin Sandra, Sancho Francisco E. P., (2003), *Morph dynamic instabilities in the surf zone, J. Geology. Res.,* 105(C10): 24071- 24087.
3- Kennedy, A.B. and Kirby, J.T., (2003). An unsteady wave driver for narrow banded waves: modeling near shore circulation driven by wave groups. Coastal Engineering, 48, 257-27.
4- Khaniki Karami, A., Sadat Kiaee, M. and Bidokhti, A. A., 2011, Evolution pattern of wave's perpendicular to the flow and sediment transport in inlets the beach using a numerical model, Twelfth International Conference on Marine Kish Industry.
5- Kraus, N.C., 1992. Engineering approaches to cross-shore sediment transport processes. *Proceeding of the short Course on Design and Reliability of Coastal Structures, attached to 23rd International Conference on Coastal Engineering, Venice, Italy,* 1992.
6-Leeuwen Van, S.M., Swart H.E. de, (2001), Intermediate modeling of tidal inlet systems: spatial asymmetries in flow and mean sediment transport, *Continental Shelf Research*22 (2002)1795–1810.
7- Milittello Adele (2003), Numerical simulation of sediment pathways at an Idealized Inlet and Ebb shoal, Proceedings coastal sediments 03, 2003.CD –ROM *by published by World scientific publishing crop and East Meets west Productions, Croups Cristi, Texas,USA.ISBN 981-238-422*.
8- Plecha, S., Silva, P.A., Oliveira, A. and Dias, J.M., (2011). Evaluation of single waves effects on the morphology evolution of a coastal lagoon inlet. *Journal of Coastal Research, SI 64 (Proceedings of the 11th International Coastal Symposium)*, 1155 – 1159. Szczecin, Poland, ISSN 0749-0208.
9- Seabergh W C, King DB, Stephens BE (2001) Tidal inlet equilibrium area experiments, inlet laboratory investigations, *Engineer Research and Development Center, Vicksburg, MS Coastal and Hydraulics Laboratory, Vicksburg.*
10- Short protection manual, part 3., Chapter 4.

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