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Impact of Long Jetties on Shoreline Evaluation (Case Study: Eastern Coast of Bandar Abbas)

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ABSTRACT

The long Jetty at Eastern coast of Bandar Abbas was designed to provide marine access from Bandar Abbas to Hormoz Island, Hormozgan province. Due to local bathymetry, the jetty was designed with relatively large length that may cause significant changes on the hydrodynamic and consequently morphological pattern in coastal area. In this study, tidal currents and wind generated waves were separately simulated using MIKE 21 numerical model in a global scale. The global tidal and wave model were calibrated using available field data and the outputs of the models were applied as the boundary conditions in the main local model. After verification of hydrodynamic model, MIKE 21/3 coupled model was applied to simulate morphological variation around the study area. In the coupled model HD (hydrodynamics), SW (spectral wave) and sediment transport modules were run concurrently and the wave-wave and wave-current interaction has been considered. Shoreline changes due to jetty were assessed and were comparing with mathematical model LITSTP (LITPACK) for more verification of the coupled model. The results of simulations and evaluation of wind effect on the current pattern revealed all three components of wind, tide and wave have significant effects on hydrodynamic regime and therefore, ignoring each component may has a large impact on the sediment transport model. Then wave propagation, wave-induced currents; tidal currents and sedimentation and erosion pattern before and after construction of the Jetty were simulated. The effect of the construction of the jetty on the current regime and sediment transport rate, were also evaluated. The morphological results showed good agreement between the two mentioned models. It can be seen that there is approximately no bed level change before construction of the jetty. In addition, the sedimentation occurs at east side and erosion at west side of jetty after construction of it. The direction of sediment transport is consistent with the dominant waves in the area.
KEYWORDS: Wave, Current, Sedimentation, Numerical Modeling, Jetty.

1. INTRODUCTION

Construction of coastal structures generally affects the coast and sea interaction and results in the changing of the hydrodynamics and morphology pattern of the project area. These changes occur due to the disturbing of the balance between all the natural factors in the surrounding environment created over the years.The assessment of this evolution and study of the shoreline deformation after construction of coastal structures is very important. The construction of a long Jetty at Eastern coast of Bandar Abbas (Fig1) designed to create access way to the supporting pier for Hormoz Island, willchange the hydrodynamic pattern and consequently the morphology of its adjacent area. Due to the bathymetric conditions, the jetty was designed with relatively large length. Moreover, the high tidal range and relatively small slope of the beach result in special hydrodynamic conditions in the study area. Therefore, evaluation of the new created conditions after construction of the long jetty has great importance and helps choosing appropriate strategies for the possible negative effects of it.

Fig. 1) Geographical Location of the Jetty Construction Site[1]

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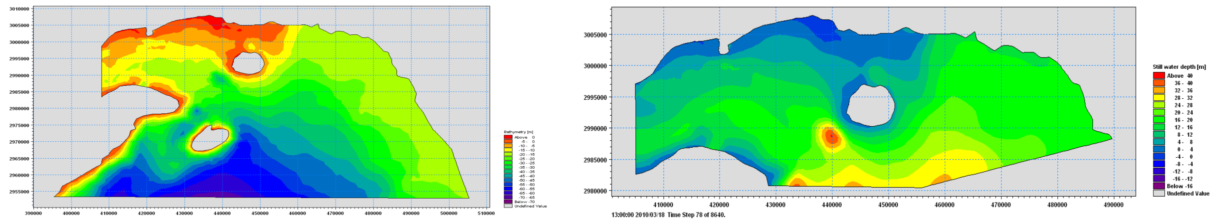
2) Construction of wave and hydrodynamic models

The first step for recognizing the factors affecting the marine environments and littoral regions is to determine the wave and current patterns in the respective regions. Effect of waves and marine currents are of utmost importance in coastal engineering. Waves and marine currents are regarded as crucial agents in formation of coastal geometry and morphology. Given the available field data in the present study, the tidal model was initially simulated using the mathematical model of Flow Model FM, and then, simulation of the wind-induced waves was carried out by means of Spectral Waves FM mathematical model on a more extensive area (general model). Then, tidal model was calibrated through comparing the model results with values of water surface fluctuations measured in Hormuz Island [2] and calibration of wave model was performed through correlating model results with wave heights measured in southern LARK Island [3]. (Fig2) illustrates domains of wave and hydrodynamic models.



(A) **(B)**

Fig. 2)A- Wave Model B- Hydrodynamic Model

2-1) Checking Accuracy of Wave Model

SW model using recorded meteorological statistics can be used for prediction of wave attributes in the cases that measurements of waves in the target site are not sufficiently available and there would be no possibility to analyze waves in boundary conditions via the measured data[4]. After constructing the wave model with Gheshm's and Bandar-Abbas' winds, information of Gheshm model was selected as the input for wave model because of being more similar to the data measured in LARK Island. There are two open boundaries in the wave model, and since wave data are not accessible, marine open boundaries were defined in the form of lateral boundaries. No wave can enter model's domain through these boundaries and the waves propagated toward these boundaries will be completely attenuated. Accuracy of any mathematical model depends on the precision of the input data[4]. Thus, accuracy of the wave generated in MIKE software is verified with field data of the wave recorded in LARK station for a 30-days period (since 09/04/2010 to 10/05/2010) prepared from Iranian Coasts Monitoring Project [3].

Spectral wave model contains several calibration parameters. The most important calibration coefficient belongs to wave white capping as the model is calibrated based on the water data at the depth of 25 meters while other physical parameters like bed (floor) friction and wave refraction caused by depth reduction do not affect the model results[4]. As observed in (Fig3) and Table 1, model simulation results with coefficient of ds=1 (coefficient of wave white capping) are acceptably precise and show excellent agreement with the measured data.

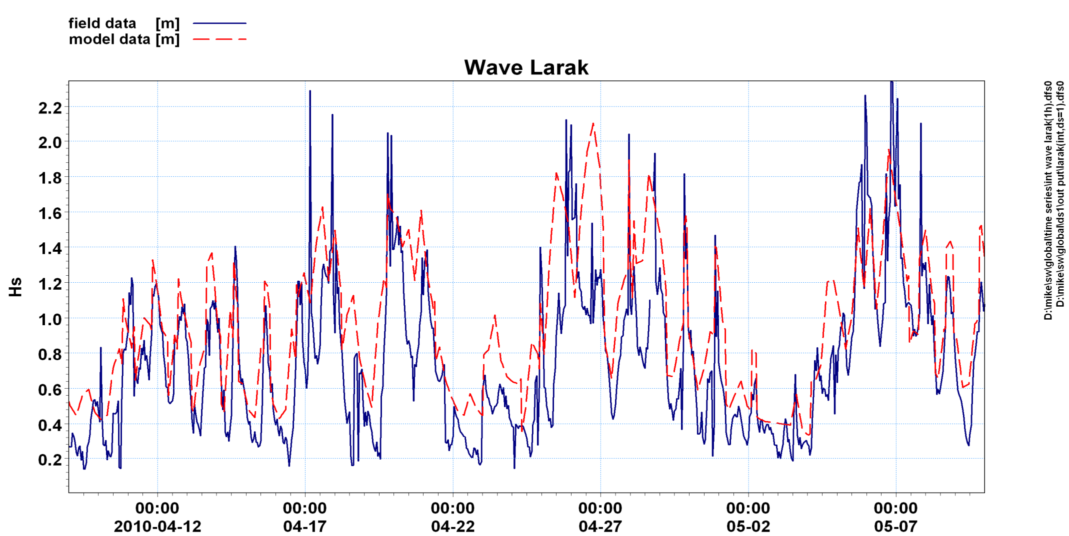


Figure3) Compartion between Field results with the results of modeling the wave in the South Island Larak

Table 1) Specifications of the statistical parameters used in evaluation of model calibration results for wave height

Model Results	Reference	Ideal Range	Normal Range	Unit	Abbreviation	Parameter
0.21	[5], [6], [7], [8]& DHI	Less than 0.3	0.2-0.5	Meter	Bias	Diagonal
0.34	[5], [6], [7], [8]	Less than 0.5	0.1-0.7	Meter	RMSE	Mean square root of error
0.954	[5], [6], [7], [8]& DHI	More than 0.8	0.75-0.9	-	CC	Correlation Coefficient
0.1	[5], [6], [7], [8]	Less than 0.3	0.15-0.35	-	SI	Dispersion Coefficient
0.25	[7]& DHI	Less than 0.7	0.36-1.27	Meter	STEXY	Standard Error

2-2) Checking Accuracy of Hydrodynamic Model

Hydrodynamic module enables performing hydraulic computations in the marine environment. This module precisely solves the second-order equations of the components in the respective domain through considering non-linear continuity and conservation of momentum equations[9].Hydrographic maps and aerial photographs of Iran's Surveying Organization with scale of 1:25000 were applied in order to determine the dry boundaries of the model. Tidal modeling data were directly used instead of field data owing to deficiency of water surface tidal data in the marine boundaries and mismatch of the time domain of these data and also necessity for coordination of the time domain in the hydrodynamic model with wave module in the local model[2].It must be noted that the processes of tide generation and accuracy verification were conducted using tidal harmonic analysis tool of MIKE 21 software for year 2010in the western boundary (DARGAHAN Region), the southern boundary (BAHMAN Port Region) and the south-eastern boundary (TIYAB Region). Bed (floor) coarseness factor was used to calibrate the model. Bed coarseness factor, defined as MANNING coefficient (m) or SHEZI coefficient in the model, is predicted as a factor for determining impact level of bed friction on the current pattern in the simulation equations. These factors which are in fact reciprocal of MANNING and SHEZI coefficients can be defined as constants for the whole surface of model or as a 2-dimesnional matrix in the model surface [9]. MANNING coefficient is applied in the case of high depth variations in the model. After many trials and errors and repeated execution of model and comparison of its results with Hormuz Station data, MANNING coefficient was chosen to be M=20 for a one-month simulation period (since 09/04/2010 to 10/05/2010). Based on the statistical calculations, correlation coefficient between field and model-estimated data is β = 0.9754 and mean error equals RMSE=0.133 cm/s. Distribution diagram of the same time interval is illustrated in (Fig 4).

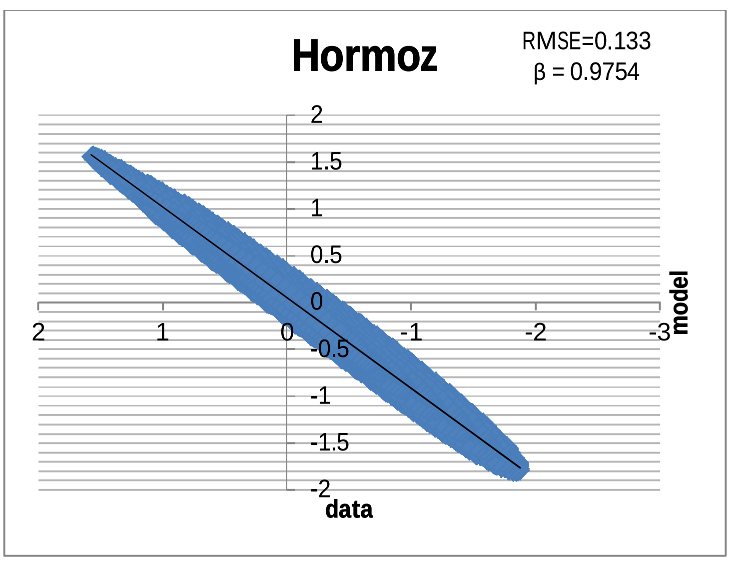


Fig. 4) Distribution diagram of water surface level for the simulation time interval

3) Construction of the Local Model

In order to evaluate the constructed jetty in eastern Bandar-Abbas coast, patterns of affecting processes are analyzed after calibration and execution of the general wave and current model. Then, wind effect on the current pattern is studied and patterns of wave-current interaction and non-linear wave-wave interaction are compared through creating the local model and using results of two general wave and current models aimed at applying the boundary conditions in the boundaries of the respective models. Having determined impact level of each process, wave propagation pattern and boundary currents caused by waves and also tidal currents as well as sedimentation and erosion models are simulated in two states i.e. before and after jetty construction with the aid of MIKE 21/Coupled mathematical model. Additionally, due to significance of sediment transport in deformation trend of coastline caused by jetty construction, this phenomenon is evaluated by means of LITSTP mathematical model of LITPACK software package as well in order to assure the accuracy of results. The simulation results are presented in the next sections. (Fig 5) demonstrates domain of the local model.

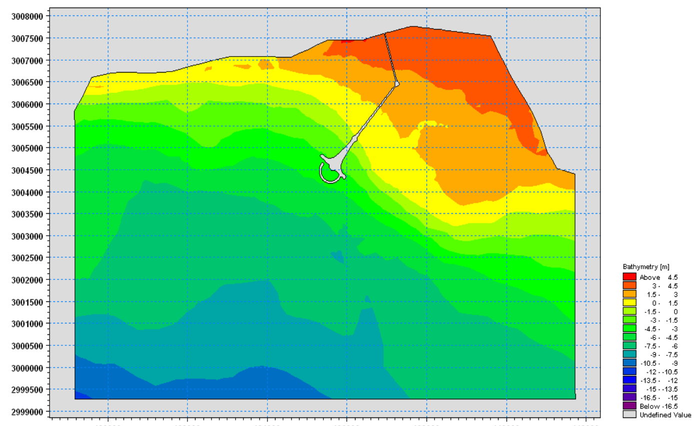


Fig. 5)Local Model

4) RESULTS AND DISCUSSIONS

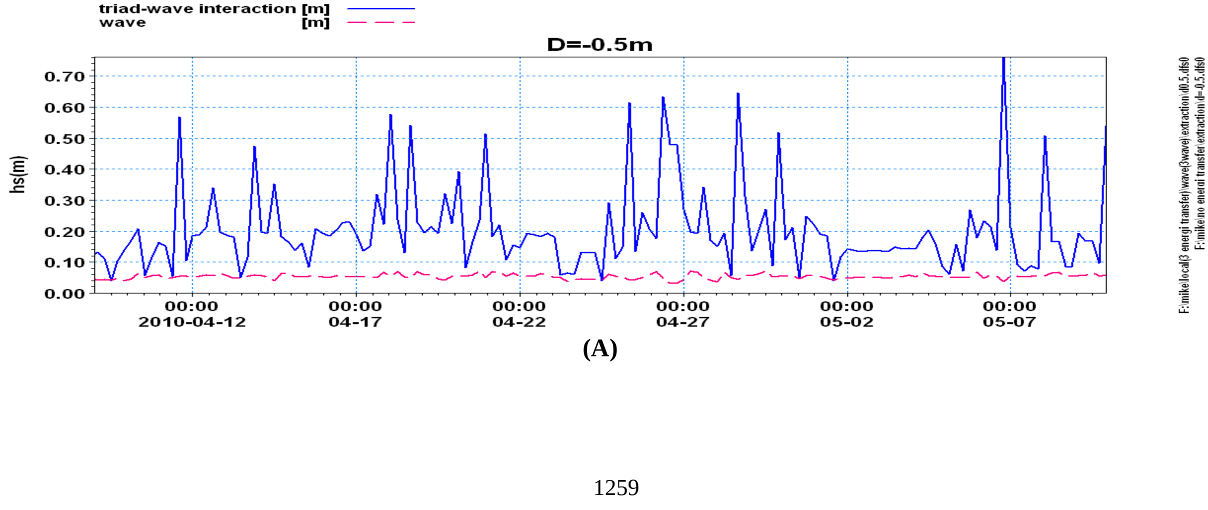
4-1) Analyzing impact of triad-nonlinear wave interaction in shallow water

In shallow waters, triad-wave interaction is the governing force in deformation of wave spectrum. In general, effect of triad interaction widens and flattens the wave spectrum leading to energy augmentation at frequencies below and above the spectral peak. Lumped Triad Approximation (LTA) is used for estimating triad interaction in the spectral wave module [10]. In this stage of research, triad-nonlinear wave interaction with default energy coefficient of the software (0.25) is used due to shallow depth of water in the regional model and small extent of the model domain [4]and effect of triad interaction is analyzed at different depths. At the depth of 0.5 meter (Fig 6-A), maximal wave height is around 0.08 meter neglecting the triad interaction while this maximal value increases up to 0.75 meter if the triad interaction is taken into consideration. Effect of triad interaction at the depth of 1.5 meter (Fig 6-b) reflects the fact that maximal wave height is approximately 0.38 (m) neglecting the triad interaction, and, ascends up to 0.5 meter if the triad interaction is not ignored. As mentioned earlier, triad interaction is the dominant phenomenon in the shallow waters and its effect diminishes as floor depth increases in a manner that activation of triad interaction will have no effect on the results at depths greater than 3 meters (Fig 6-c).

4-2) Wind Effect on the Current

To analyze wind effect on the current in the hydrodynamic module, the model is studied in two states: considering the wind effect, and, neglecting the wind effect (Fig 7). Current cycle shows the current and wind involved in the model as well as the current model neglecting wind effect within the jetty construction area in the local model and for one time step. Having a more meticulous look into the results, it can be observed that current direction is affected by wind in shallow points.

(Fig 8) represents wind effect on current velocity at different depths. At the depth of 1.5 meter (Fig 8-a), maximal current velocity induced by wind is 0.15 m/s and maximal current velocity neglecting wind effect declines to less than 0.1 m/s. Wind effect on current velocity decreases with increasing depth, and difference of maximal wind velocities between the two states reaches 0.03 at the depth of 3 meters (Fig 8-b) and to less than 0.01 meter at the depth of 4.5 meters.



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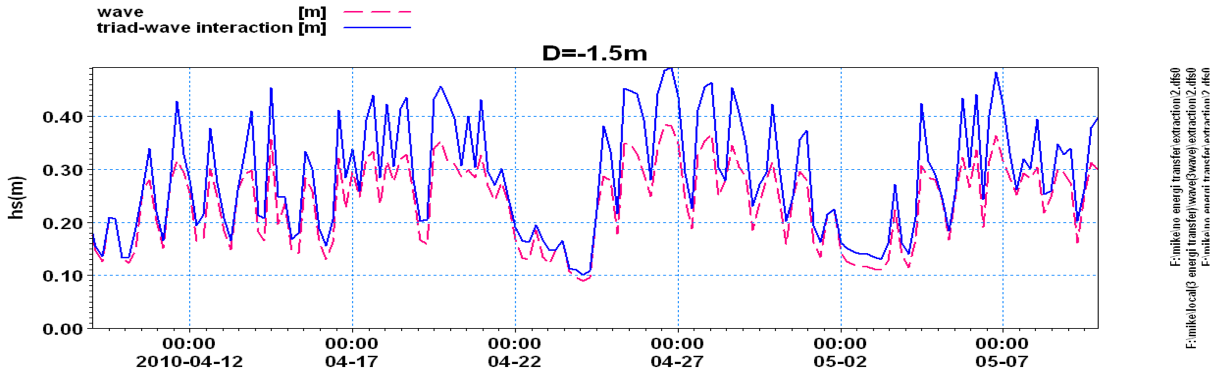

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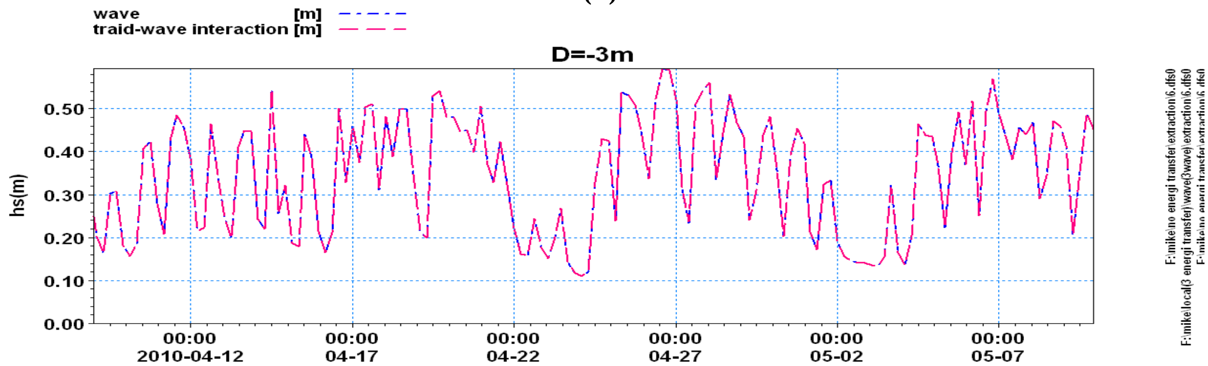
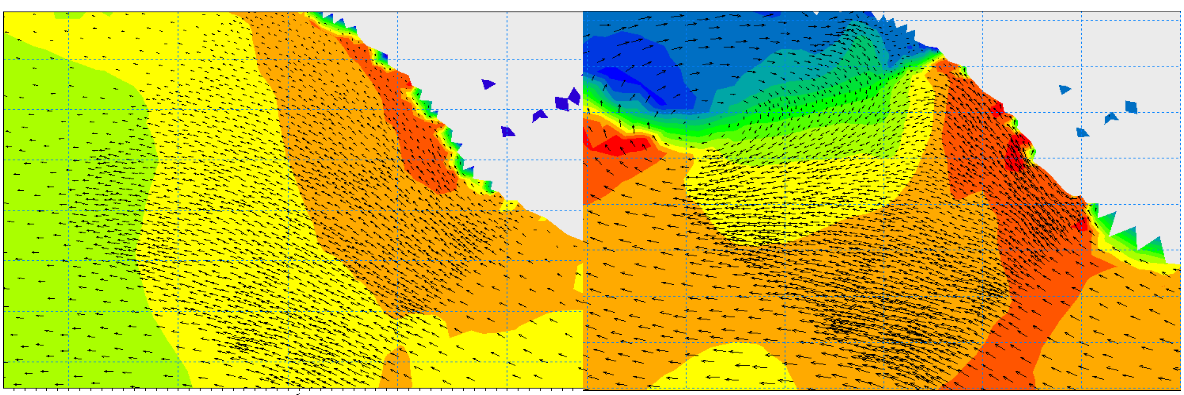


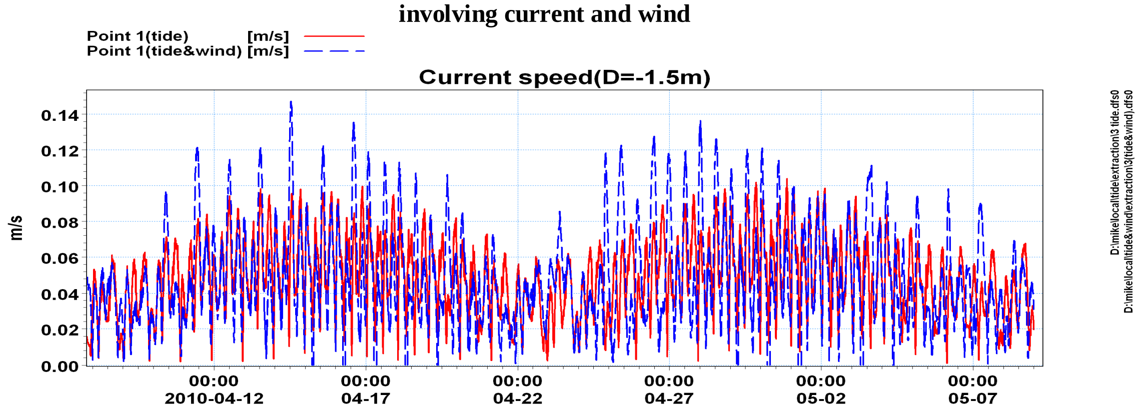
(C)

Fig. 6) Effect of triad- wave interaction at the depths of (A)-0.5 meter, (B)-1.5 meter, and (C)-3 meters



(A) (B)

Fig. 7) Wind effect on current pattern in the regional model: (A)-Current without wind effect, (B)-The model involving current and wind



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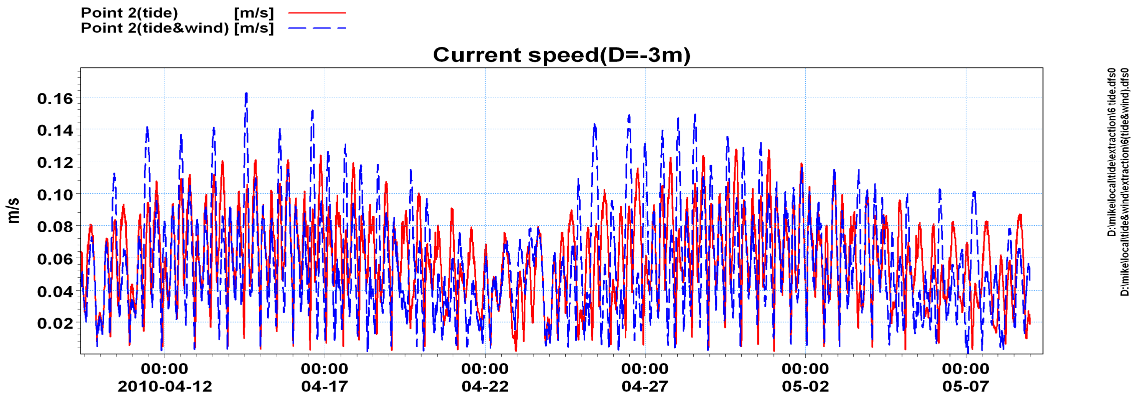

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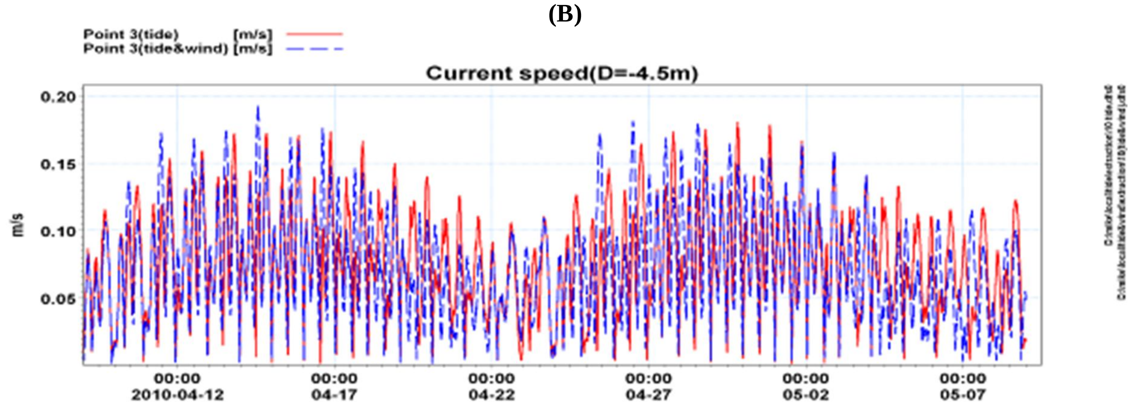


(C)

Fig. 8) Wind effect on current in the local model at different depths (A)-1.5 meter, (B)-3 meters, and (C)-4.5 meters

4-3) Construction of Coupled Model

Through analysis of the wind effect on the current pattern and also comparison of waves and current interaction in different points, it is seen that all three components namely wind, tide and waves play significant roles in the boundary flow pattern. Thus, neglecting any of these components might severely affect transport model of boundary sediments. Accordingly in this stage of research, MIKE 21/3 Coupled Model FMmodule[11], is used, keeping into mind the aforementioned features of different modules available in MIKE software packages. In this software package, three required modules i.e. hydrodynamic, spectral and sediment transport modules are simultaneously run and wave-wave and wave-current interactions can also be taken into account.

The time interval in the respective region is 30 days (since 9/4/2010 to 10/5/2010) the same as the hydrodynamic module because the tidal data applied to the boundaries in the local model are extracted from the hydrodynamic and spectral wave modules. Time steps of 0.25 seconds for the hydrodynamic module, 30 seconds for the wave module and 3600 seconds for the sediment transport module were assumed after great deal of trials and errors and because of the numerous modeled points around the jetty. According to the studies conducted in the design of Hormuz Island's marine access [12], average granular size of sediments in the region (d_{50}) is 0.2 mm and the deposits are classified as unconsolidated and sandy sediments.

4-4) Analyzing Effect of Jetty Construction

After adjustment and execution of Coupled Model, the results of applying this model and coastal conditions before and after jetty construction are discussed in this stage. (Fig 9) marks the position of the respective points.

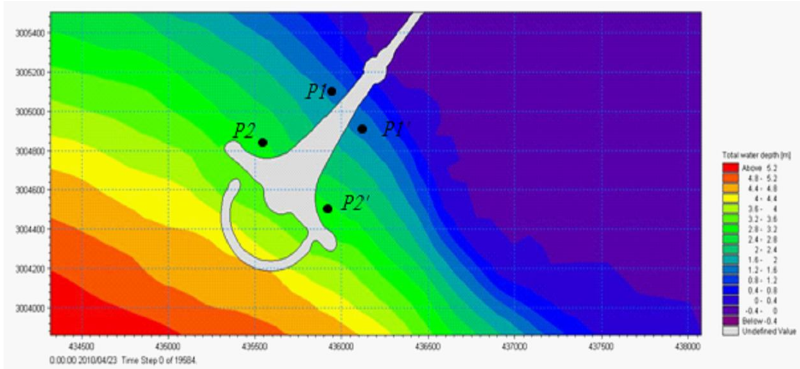
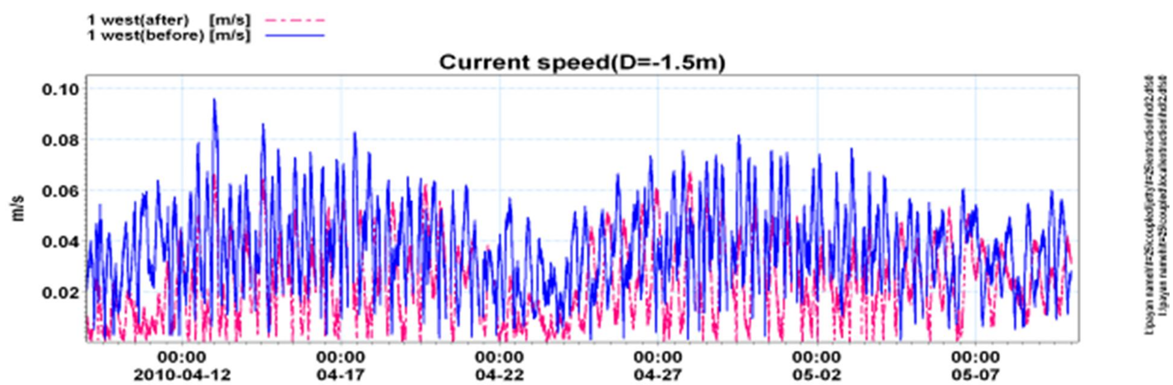


Fig. 9) Position of the Respective Points

4-4-1) Hydrodynamic Module

Hydrodynamic module has numerous outputs; the most important ones being current velocity and direction. In the subsequent parts, current velocity is analyzed at different depths and in two states: before and after jetty construction.

As observed in (Fig10 and 11), current velocity did not considerably change at different depths before jetty construction and maximal current velocity equaled 0.12 m/s. However, after jetty construction and depending on the position of the target points, current velocity decreases in eastern and western sides of the jetty. The minimal current velocity reduction compared to pre-construction state occurs at the depth of 1.5 meter, and, reduction in current velocity compared to the former state (before jetty construction) is intensified as the floor depth increases.



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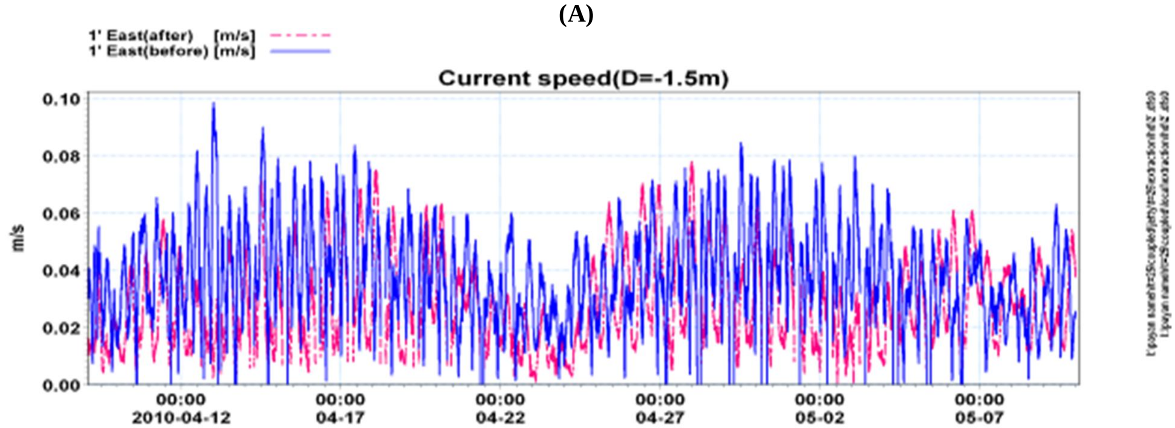
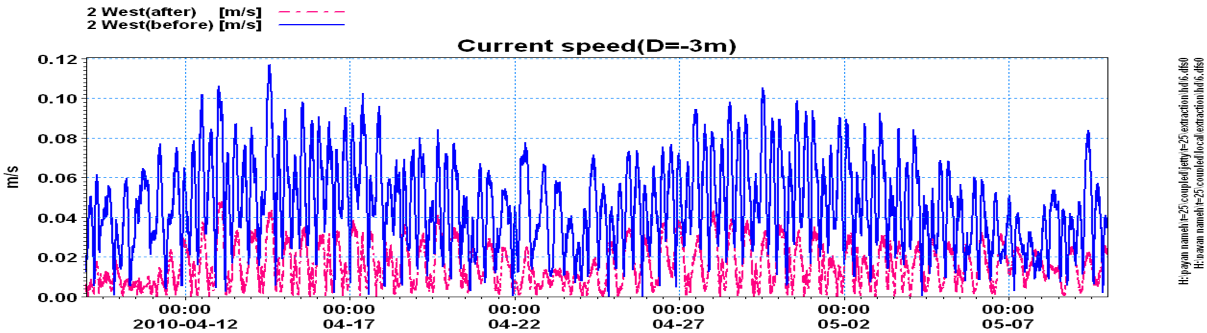


(B)

Fig. 10) Comparison of current velocity before and after jetty construction in (A)- point P1, west of jetty; (B) point P1`, east of jetty



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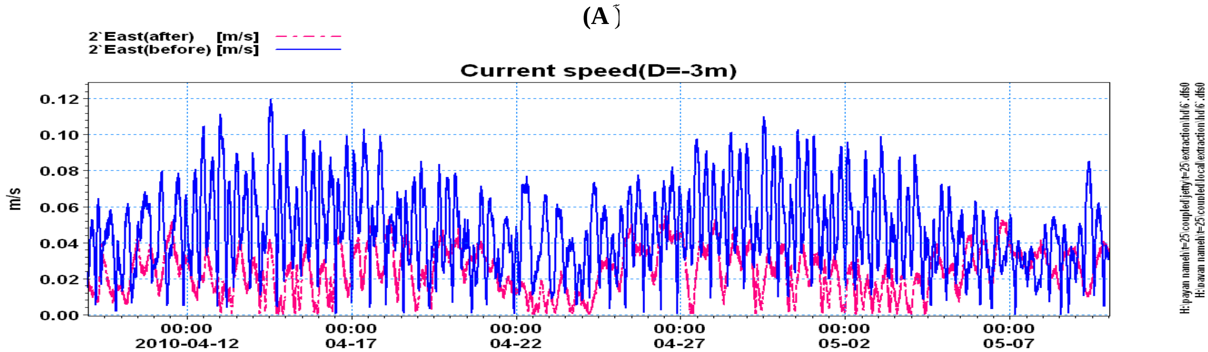
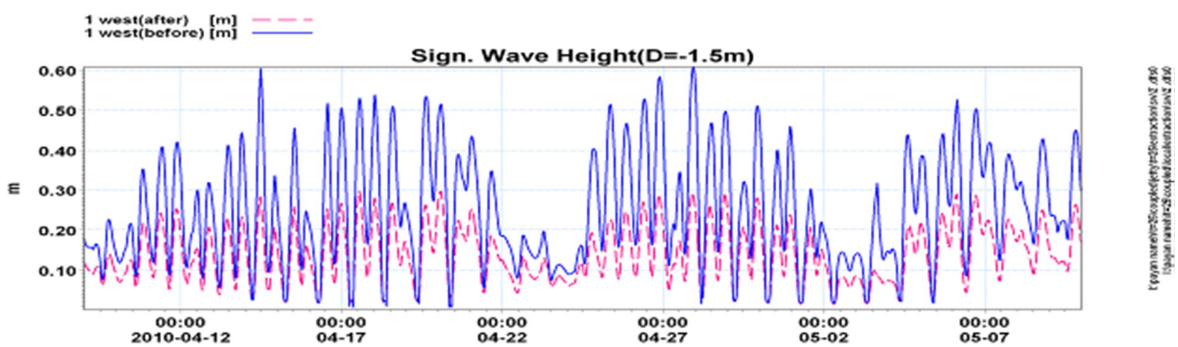


(B)

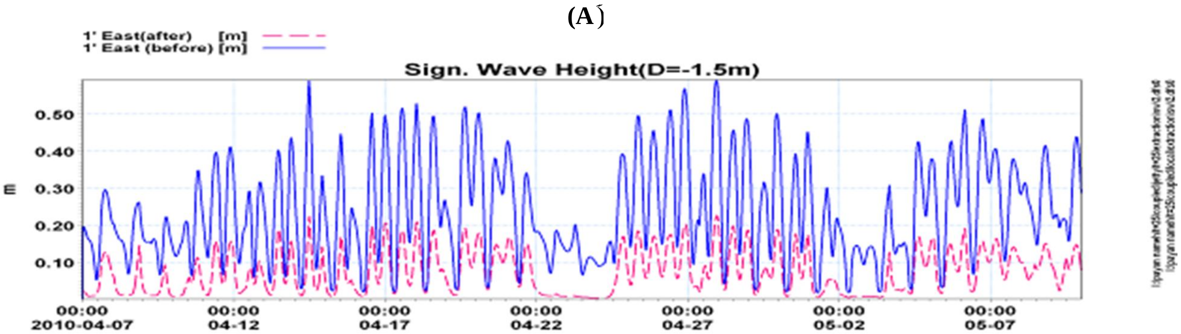
Fig. 11) Comparison of current velocity before and after jetty construction in (A)- point P2, west of jetty; (B) point P2`, east of jetty

4-4-2) Spectral Wave Module

Comparison of wave height in eastern and western sides of jetty (points P1 and P1`) is illustrated in (Fig 12)between two states i.e. before and after construction at the depth of 1.5 meter. Maximal wave height before construction is 0.6 meters and wave height value remarkably decreases at both sides following the construction causing the value to reach 0.3 meter in the western side within the same time step (Fig 12-A). The wave height drops to less than 0.22 meter in the eastern side (Fig 12-B).



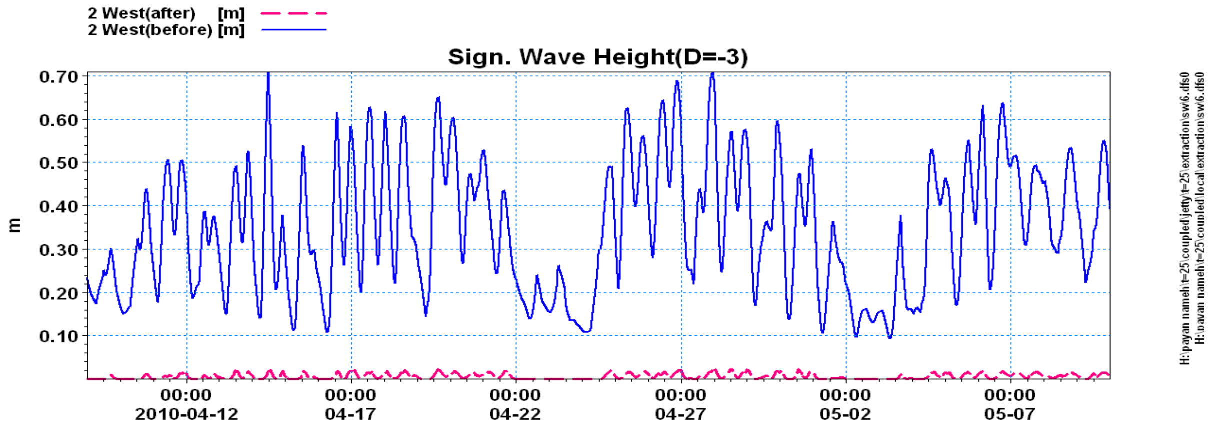
(A)



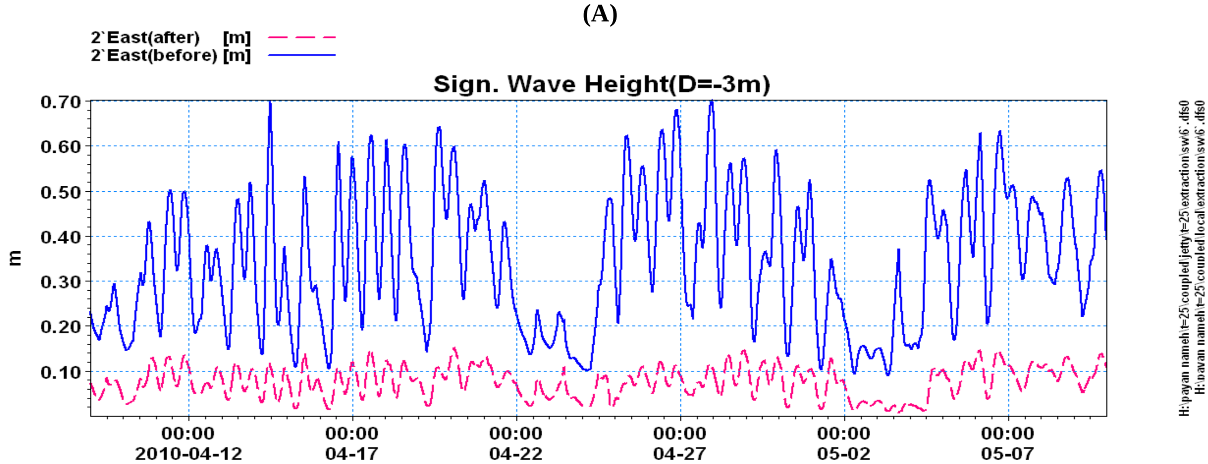
(B)

Fig. 12) Comparison of characteristic wave heights before and after jetty construction in (A) point P1, western side; (B) point P1`, eastern side

(Fig 13) shows comparison of wave heights (points P2 and P2`) in the eastern and western sides of jetty at the depth of 3 meters for two states: before and after jetty construction. Maximal wave height is 0.7 meter in the state before jetty construction, and following its construction, wave height in the same time step reduces to less than 0.02 and 0.15 meters in the western and eastern flanks, respectively (Fig 13-A and 13-B).



(A)



(B)

Fig. 13) Comparison of characteristic wave heights before and after jetty construction in (A) point P2, western side; (B) point P2`, eastern side

4-4-3) Comparison of sedimentation results in LITSTP and Coupled Modules

Results of the sedimentation model were compared in Coupled and LIPSTPmodules[13], before jetty construction in the local model in order to control accuracy of the numerical method results. (Fig 14) shows positions of the target points.

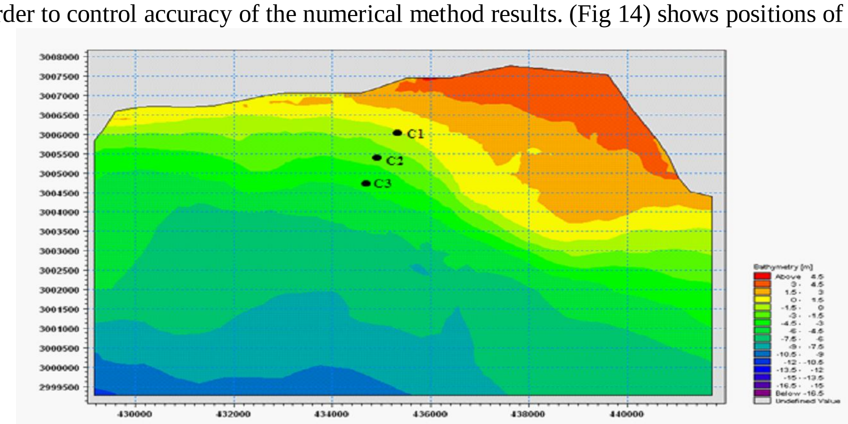


Fig. 14) Positions of points for comparison of LITSTP and Coupled models

Since the Periodic position information of two model Coupled and Litstp in points C1, C2, C3 are almost the same values, and abundance diagrams are also correlated together, thus Modeling accuracy is more evident. You can see these resultsinTable2:

Table 2: Conclusion the results of statistical comparisons (The amount of sediment accumulation of two model Coupled and LITSTP)

QTx(m^3/m)			Number of points
R^2	RMSE	CC	
0.9951	0.1226	0.975	Point C1
0.9851	0.0686	0.9726	Point C2
0.9845	0.0566	0.997	Point C3

4-4-4) Analysis of sedimentation states before and after jetty construction

Variations of the floor level measured by Coupled model at the depth of 1.5 meter (points P1 and P1`) are compared in two states i.e. before and after jetty construction (Fig 15). According to the figure, nearly 0.8 cm of erosion has occurred in a 30-days interval before construction. After construction, erosion decreases to 0.2 cm in the western side while floor level variations are negligible in the eastern side. It can be concluded that jetty construction contributes to revival of coast in the respective points at both sides of the structure.

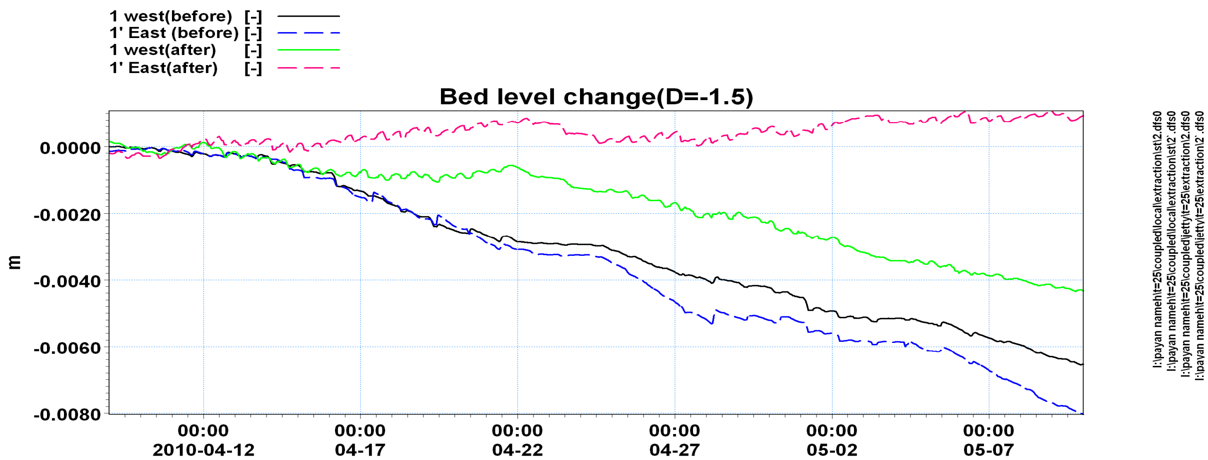


Fig. 15)Bed level changes before and after the construction of the jetty in 1.5 m depth (Cut lines correspond to the East side and continuous lines correspond to the west side of jetty)

(Fig16) represents floor level variations in P2 and P2` points of eastern and western sides at the depth of 3 meters for two states: before and after jetty construction. Floor level variations are very slight before jetty construction while 4 cm and 1 cm sedimentations are respectively recorded after construction in the western and eastern sides during a 30-days interval. As observed, floor variations diminish with increasing depth before jetty construction while erosion and sedimentation phenomena are intensified respectively in the eastern and western sides after jetty construction.

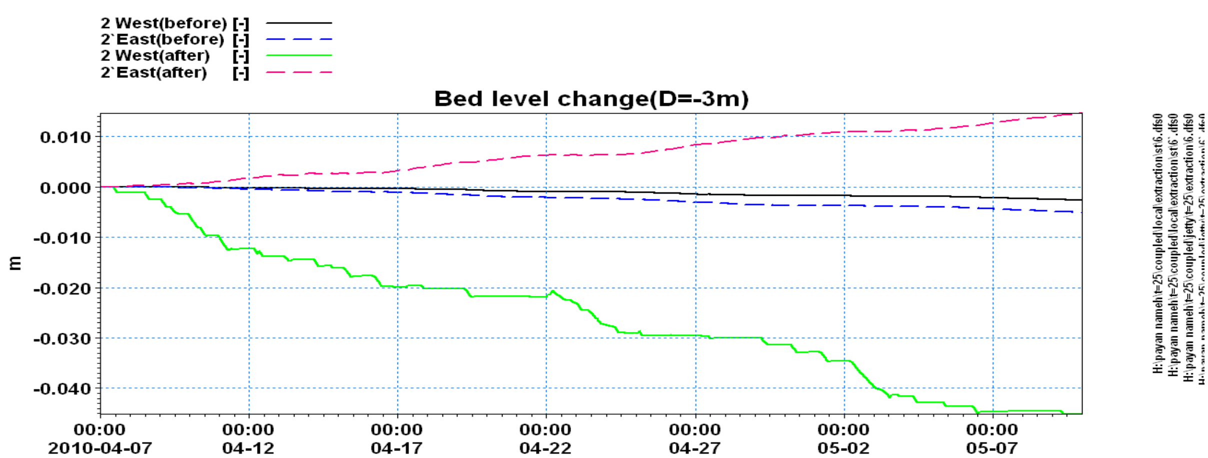


Fig. 16)Bed level changes before and after the construction of the jetty in 3 m depth (Cut lines correspond to the East side and continuous lines correspond to the west side of jetty

5) Conclusion

Assessment of triad interaction effect in shallow water is suggestive of the fact that triad-wave interaction dominates the deformation of wave spectrum in such waters and wave height considerably increases if triad interaction is taken into account. Assessment results of wind effect on pattern of the current induced by tides indicate that current velocity and direction are affected by wind in shallow waters, and, wind effect on the current dwindles as depth increases. Thus, neglecting the wind effect might greatly affect the prediction of the tide-induced current model.

According to the comparisons made between model results and the data measured in the corresponding points, the models applied in the current research are proved to have acceptable validity.

Jetty construction will change the direction of tide-induced current; as a result, current direction varies in different points at both sides of jetty.

The current induced by north-eastern and south-western winds flow toward the sea recurrently after collision to the jetty structure. Comparison of wave climates before and after jetty construction implies that wave height rises with increasing floor depth before construction, yet following jetty construction, wave height remarkably declines at both sides considering the positions of points.

Prior to construction, floor level variations were extremely negligible and tended to zero with further increase in the floor depth. However, sedimentation and erosion emerge as the dominant phenomena respectively in the eastern and western sides following the jetty construction. Through analyzing direction of sediment distribution, net movement of sediments is revealed to be in the same direction as the wave progression course.

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