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CASE STUDY

Investigation of sediment transport pattern and beach morphology in the vicinity of submerged groyne (case study: Dahane Sar Sefidrood)

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ABSTRACT Marine structures, such as Groynes, Sea walls and Detached Breakwaters, are constructed in coast of area to improve coast stability against bed erosions due to changing wave and current pattern. Marine mechanisms and interaction with the hydraulic structures need to be intensively studied. Groynes are one of the most prominent structures that are used in shore protection and littoral sediment. The main hydraulic function of the groyne is to control the long shore current and littoral sediment transport. This structure can be submerged and provide the necessary beach protection without negative aesthetic impact. However, for submerged structures adopted for beach protection, the shoreline response to these structures is not well understood. The objective of this study is to predict sediment transport in the vicinity of submerged groyne and comparison with non-submerged groyne focusing on a part of the coast at Dahane Sar Sefidrood, Guilan Province, Iran, where serious coast erosion has been occurred. The simulations were designed using a one-line model which can be used as a first approximation of shoreline prediction in the vicinity of groyne. The results of the proposed model are compared with experimental data to determine the shape of the coast. The results of predicted beach deformation show that when submerged groyne construct in the beach, sediment accumulation will be slightly less than the non-submerged groyne; because transfer coefficient for the submerged groyne is more than non-submerged groyne. This result will cause more sediment passing on submerged groyne. Finally, the result of the present study show that using submerged groyne is an efficient way to control the sediment and beach erosion without causing severe environmental effect on the coast.

KEYWORDS submerged groyne, non-submerged groyne, beach morphology, Dahane Sar Sefidrood, sediment transport

1 Introduction

Awareness of environmental issues in coastal areas, including protection of natural ecosystems and coastal environments, due to the increasing population along the coast is important. Since the beaches, especially sandy beaches can be eroded by water waves; the prediction of shoreline changes in the coastal areas affected by the severe storms, increases coastal engineers' skills for designing efficient structures in coastal areas.

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In the past several investigations have been conducted in to find the effects of groyne parameters on the change of shoreline:

Hanson and Kraus experimentally investigated the effects of a series of three groynes on shore evolution and proposed a numerical model (Genesis). Their results were accordance with the results of the physical model [1]. Badiei et al. conducted a physical experiment on the effects of groynes on shore morphology; the tests were carried out at two different wave basins with the beach lengths of 8 and 28 m, respectively. Finally they proposed a detailed morphological and hydrodynamic database which can be used for calibration and verification of numerical morphology models [2]. Gungordu and Otay proposed a numerical model for prediction the shoreline changes in the vicinity of a groyne employing only long shore sediment transport [3]. Leont'yev conducted a study on morphological changes due to coastal structures such as a groyne, a detached breakwater and a navigable channel. Also in that paper, a coastal area model was introduced for describing the evolution of 2DH bottom topography during a given storm attacking a beach, both in the natural state and in the presence of structures [4]. Ozolcer et al. studied the effects of straight groyne parameters on the amount of accretion in a physical model in wave basin using regular waves. They also carried out a numerical model which depends primarily on a CERC model to examine the effects of some of the various groyne parameters (length and spacing) and wave parameters (wave height, wave period and wave angle) on the accretion of area protected by straight groyne studied in a physical model. Finally, the results of a numerical model are compared with data that were obtained by deep sounding measurements at Carsibasi coasts, Trabzon province in Turkey [5]. Gayan et al. conducted a study on the impact of rubble mound groyne structural interventions in restoration of Koggala lagoon, Sri Lanka. They also evaluated the current situation of the lagoon and proposed alternative structural intervention for minimization of seawater intrusion and subsequently improved lagoon ecosystem [6]. Recently, Lashteh Neshaei and Afsoos Biria studied the effects of groyne Impact on beach and scour risk in Anzali and Astara coast. They also carried out shoreline prediction in vicinity of groyne using Mike21-st [7,8]. This study revealed that the beach profile could face remarkable change in the vicinity of groyne, preventing the severe shoreline erosion.

After extensive research on a part of the coast at Dahane Sar Sefidrood, it has been revealed that this area is at high risk for beach erosion; therefore, it was selected for this study (see Fig. 1). It is noteworthy that, the coastal villages of Astaneh Ashrafieh, due to sea-level rise, are at risk of flooding. Sea-level rise in some village of this city i.e., Dahane Sar Sefidrood are very serious as many houses have been exposed to destruction. Also, rising sea-levels have caused massive damage to hunters in these areas. Sea-level rise in the coast of the city is an important issue that must be considered; otherwise, the city will face further damage, and if sea-level rise continues on the coast of this city, residents will be facing a lot of problems in future. Threat and endangerment of human life due to sea level rise at Dahane Sar Sefidrood, are flown in Figs. 2–4.

2 Data collection procedure

The available data in this study area are as follows.

Fig. 1 Study area map

Fig. 2 Coastal building exposed to waves

Fig. 3 Coastal road exposed to waves

Fig. 4 Submerging wheat silos due to sea level rise

2.1 wave characteristics in deep-sea areas

Information and specifications concerning the deep water wave at the study area including height, period and direction based on the results of the ISWM (Iranian sea wave modeling) project have been used as the original data. The second phase of the simulation is based on the project of Iranian Seas Waves Defined by the Caspian Sea Ports and Shipping Organization and then conducted by the Iranian National Oceanography Centre, together with the Danish Hydraulic Institute. The second phase of the project, covers the period of January 1992 to August 2003, First set, data for simulation, such as wind data (measured by satellite, synoptic stations and meteorological model outputs), wave data (satellite), bathymetric data, tides, sea level changes and frost were gathered and analyzed, and then using Mike 21 which is a third-generation model, the wave from wind field has been calculated. Calibration and verification of the model using wind and wave data, and the accuracy of the measured results are performed in an appropriate manner. After this stage, statistical analysis was performed using EVA (Extreme Value Analysis) and statistical characteristics of waves with different return periods have been performed and stored in a database [9]. Figures 5 and 6 show the wave rose and periods measured in the study area.

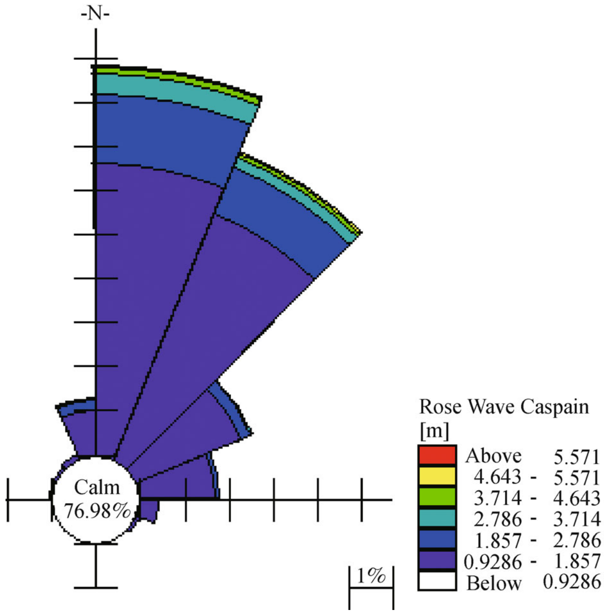

Fig. 5 Wave rose based on the results of ISWM [9]

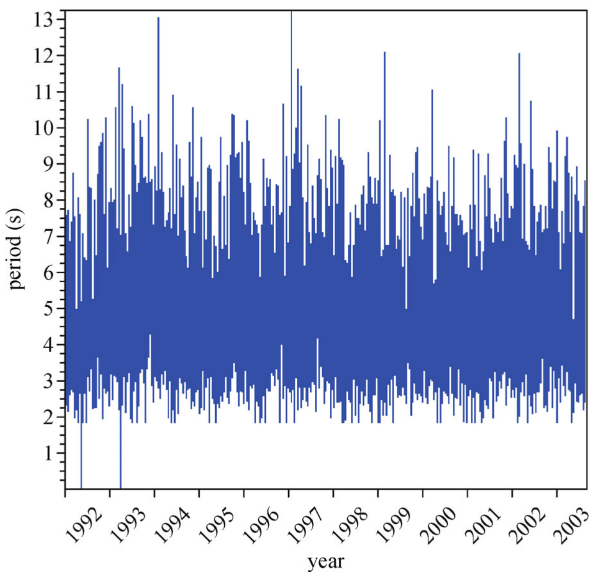

Fig. 6 Wave period based on the results of ISWM [9]

2.2 Aggregation properties of coastal sand

Beach sediment grain size after sampling and testing is specified, the most common parameter of size distribution of sandy sediments of the coastal area is d50.

Also, to obtain the average particle diameter from different parts of the sea bed; 10 soil samples were taken from the study area. Grading curve of soil sample is show in Fig. 7.

2.3 Shore and seabed topography

The first and most fundamental data about deformation of the coastline is information about the hydrograph of the region. Figure 8 shows the bathymetry map of the study region. In this study, Hydrographic Map of Dahane Sar sefidrood (1991), which was prepared from Mapping Organization of Iran whit 1:10000 scales, has been used [10].

Therefore, the data used in this study include bathymetry, deep water wave information (height, period, direction of waves) and particles size distribution. Figure 9 shows the aerial map of the study region.

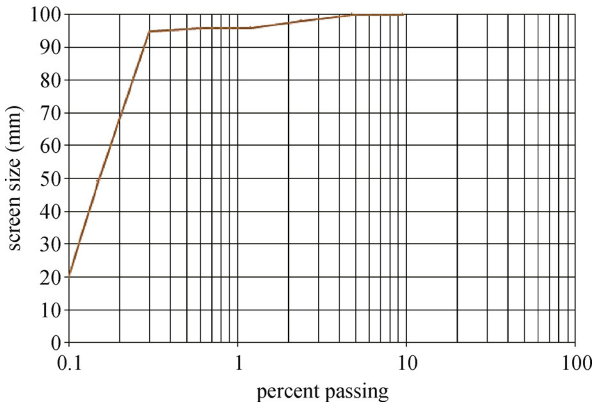

Fig. 7 Grading curves of soil in the study area

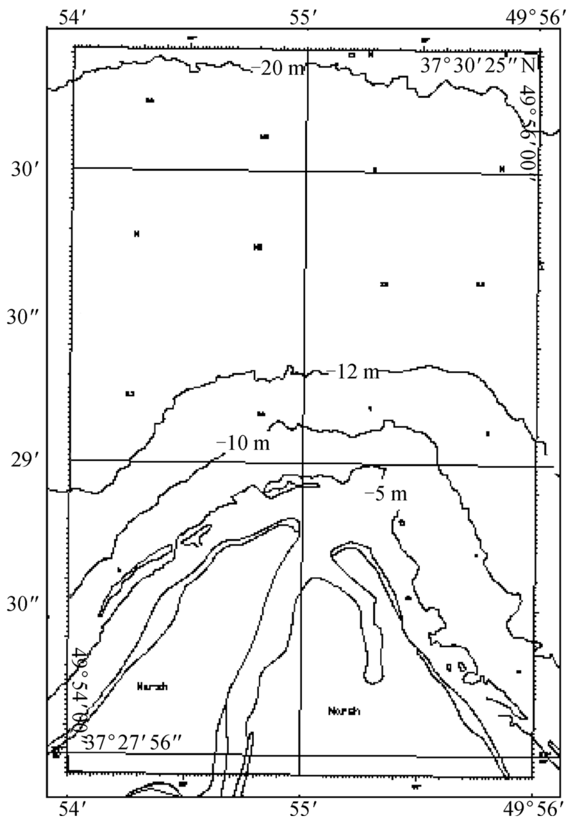

Fig. 8 Bathymetry of the study area

3 Methodology

3.1 Long-shore sediment transport rate

There are numerous equations to predict the long shore sediment transport rate. By analyzing this formula, the following two equations were employed in this study:

The most common approaches for calculating the time-averaged net sediment transport rate is the CERC equation which reads [12]:

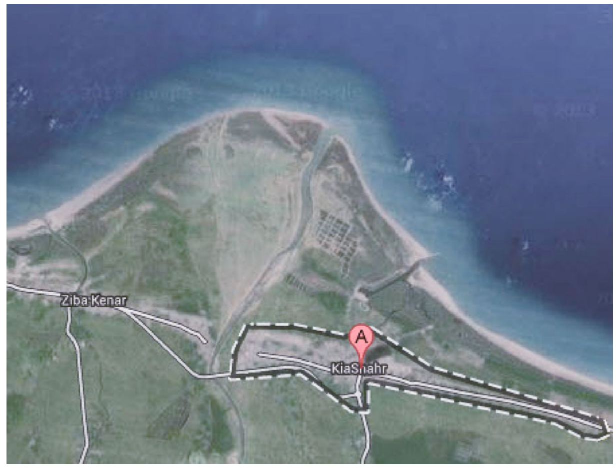

Fig. 9 Aerial photograph of the study area [11]

$$Q_{\mathrm{CERC}} = K\left[\frac{\rho\sqrt{g}}{16k^{\frac{1}{2}}(\rho_s-\rho)(1-n)}\right]H_b^{\frac{5}{2}}\sin 2\alpha_b, \qquad (1)$$

where K is the breaking index, ρ and ρ_s are specific gravity of water and sediment particles respectively, g is gravity acceleration, n is porosity of sediment particles, H_b is the breaking wave height and α_b is the breaking wave angle.

This method is based on energy and sediment transport which is related to the energy released from the breaking waves. Among the major drawbacks of this method is the lack of consideration of particle size and slope of the seabed. In addition, in this method, sea currents which are not generated due to wave breaking and are not similar to the current due to the tide, are not covered.

Kamphuis (1991) proposed different equation [13]:

$$Q_{\mathrm{kamphuis}} = 6.4\times10^4 \times H_{sb}^2 T_p^{1.5} m_b^{0.75} D_{50}^{-0.25} \sin^{0.6} 2\alpha_b, \qquad (2)$$

where H_{sb} is the breaking wave height, T_p is wave period, m_b is the bed slop in breaking line, D_{50} is the particle average size and α_b is the breaking wave angle.

This formula considers particle size and slope of the seabed.

3.2 Analysis of wave transmission coefficient

Since the wave transmission coefficient is directly related to the entrapment of sediments, therefore in this section, the analysis of wave transmission coefficient and the effect of dimensionless variables on groyne with various crests are examined. Figures 10 and 11 show the parameters of non-submerge and submerged groyne used in the calculation process.

Several studies have been conducted by Seelig (1980), Powell and Allsop (1985), Daemrich and Kahle (1985),

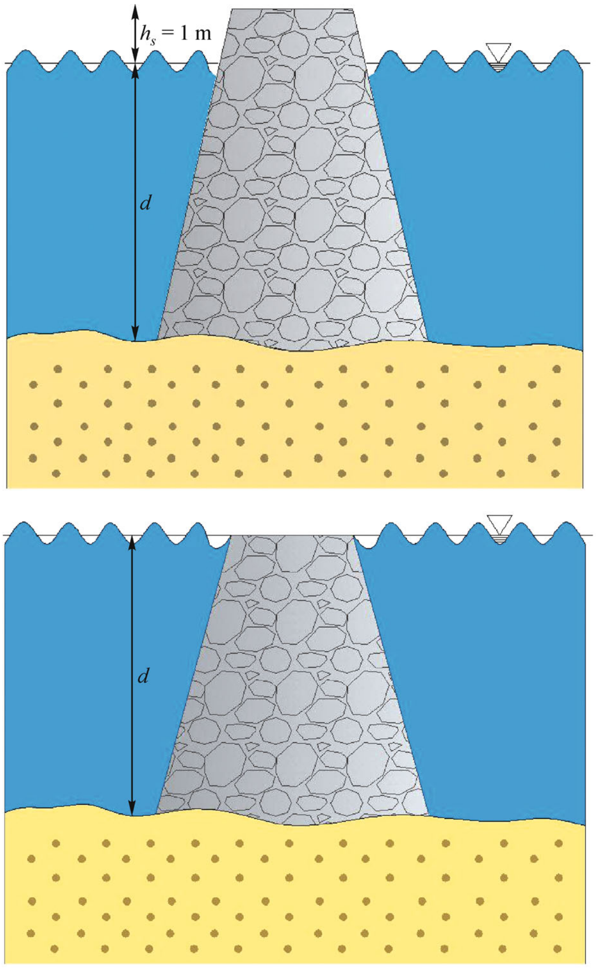

Fig. 10 Non-submerged groyne in the calculation process

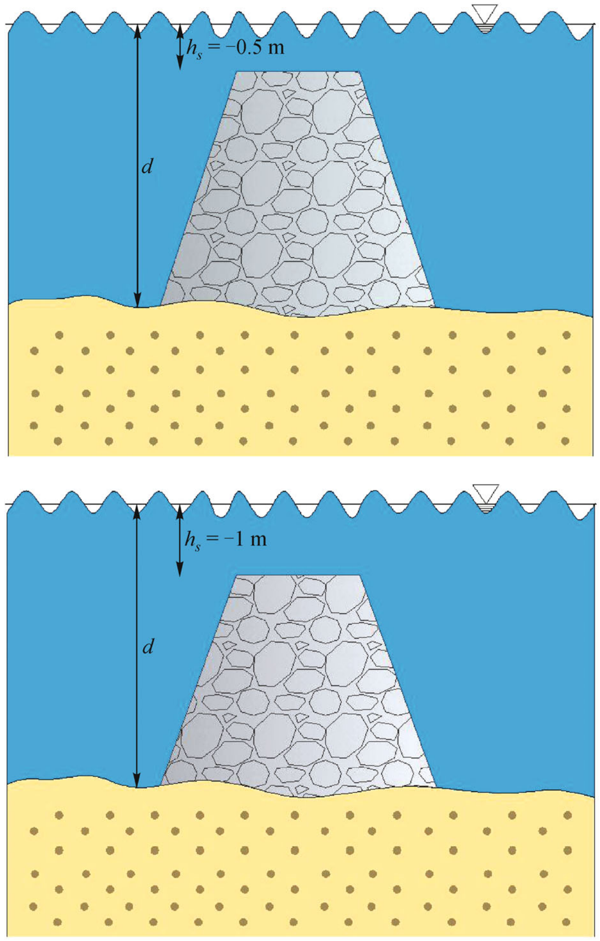

Fig. 11 submerged groyne in the calculation process

Ahrens (1987) on the wave transmission coefficient. In this study, following the investigation of Angremond et al. coefficient of wave transmission on submerged structures is used based on this equation [14–18]:

$$K_t = b_1\left(\frac{h_s}{H_i}\right) + b_2\left(\frac{B}{H_i}\right)^{b_3} . \left(1 - \exp\left(b_4 \times \xi\right)\right), \tag{3}$$

where h_s is the distance between the water and the structure crest, H_i is wave height, B is the crest width of groyne. ζ is Iribarren's number, and b_1–b_4 are coefficients calculated using nonlinear regressions. Equation (4) predicts the wave transmission coefficient recommended for a more reliable range of the structure of $4.4 < B/L < 0.08$:

$$K_t = 0.17\left(\frac{h_s}{H_i}\right) + 2.84\left(\frac{B}{H_i}\right)^{-0.26} . \left(1 - \exp\left(-0.14 \times \xi\right)\right). \tag{4}$$

Based on the output of numerical results, the wave transmission coefficients are estimated for submerged and non-submerged groynes.

As can be seen in Figs. 12 to 15, the wave transmission coefficient in terms of dimensionless variables were analyzed and based on the results, dimensionless parameter variations and the effect on the wave transmission coefficient can be expressed as follows:

1) $\frac{h_s}{H_i}$ and $\frac{B}{H_i}$ has linear and multilinear relationship with the wave transmission coefficient.

2) If submergence ratio increases, more energy is transferred from the groyne.

3) By increasing the wave steepness, the transmission coefficient is reduced.

4) With the increasing of Iribarren number, the wave transmission coefficient increased accordingly.

5) Dimensionless parameter crest width to wave height has a direct effect on transmission coefficient. When the wave steepness increases, the wave transmission coefficient decreases. Wave steepness parameter for the submerged groyne was higher than non-submerged groyne.

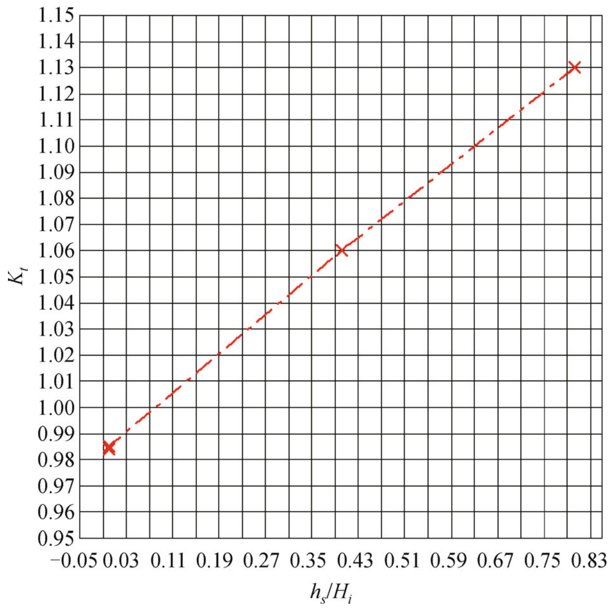

Fig. 12 Variation of wave transmission coefficient parameters against h_s/H_i

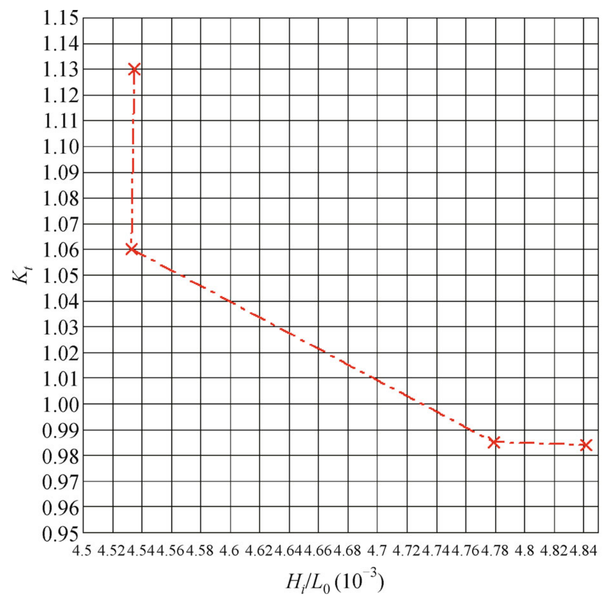

Fig. 14 Variation of wave transmission coefficient parameters against wavelength dimensionless parameter

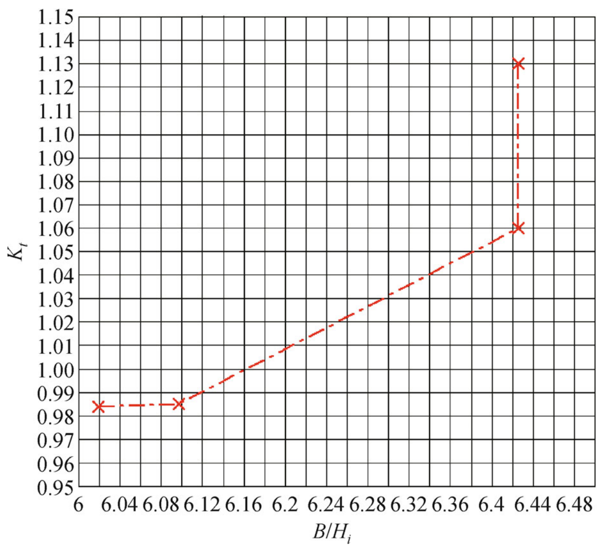

Fig. 13 Variation of wave transmission coefficient parameters against B/H_i

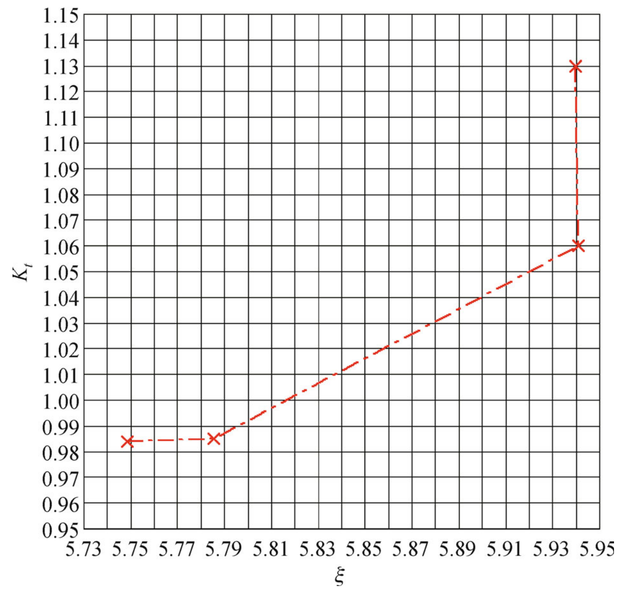

Fig. 15 Variation of wave transmission coefficient parameters against Iribarren's number

3.3 Calculating the deformations of coast in the vicinity of groynes

Assuming discharge, in x and y directions to be linear, using multilinear and network theories, coast deformation based on continuity and momentum equations can be calculated.

If the long-term sediment budget for a coast is considered, it will often be found that the dominant term is due to variation in the long shore sediment transport, along the coast and the development of coastline can therefore be modeled by calculating the coastal erosion or accretion from the long shore sediment transport. The simplest coastline model, i.e., the one-line model, assume that the coastal profile is maintained constant but is shifted in the onshore or offshore direction as the result of erosion or accretion .The first calculations with the coastline model were made by Pelnard-Considere who used an analytical solution to Eq. (4). In many cases, this technique can be used to obtain a first estimation of the morphological development [19].

$$\frac{\partial y}{\partial t}=\frac{-1}{(1-n)h_p}\frac{dQ_l}{d\left(\frac{\partial y}{\partial x}\right)}\frac{\partial\left(\frac{\partial y}{\partial t}\right)}{\partial x}=\frac{-1}{(1-n)h_p}\frac{dQ_l}{d\left(\frac{\partial y}{\partial x}\right)}\frac{\partial^2 y}{\partial x^2}. \quad (5)$$

This is the equation which is solved in order to make a coastline development model. It is a parabolic partial equation which must normally be solved numerically. The establishment of the coast orientation and the long shore sediment transport will require a large number of single calculations of the long shore transport rate and it will normally not be possible to establish any analytical relationships.

The boundary condition at the groyne according to analytical solution to coastline model is used in this study. Therefore the boundary conditions are:

$$\left\{\begin{array}{l}\frac{\partial y}{\partial x}=0.15=Y_0' \ for \ x=\pm 0\\ \text{and}\\ Y\rightarrow 0 \ for \ \rightarrow x\rightarrow \pm\infty\end{array}\right\}. \quad (6)$$

With these boundary conditions, Pelnard-Considere proposed the solution for predicting of the coast line:

$$Y=Y_0'\frac{1}{\sqrt{\pi}}\left[\sqrt{4K_1 t}\exp\left(-\frac{x^2}{4K_1 t}\right)-x\sqrt{\pi}\left(1-F\left(\frac{x}{\sqrt{4K_1 t}}\right)\right)\right]. \quad (7)$$

Therefore, due to wave breaking, transport of sediment along the coast begins to move, and if a barrier to be built along this current, sedimentation happen behind the beach and finally beach deformation is changed. In Shore Protection Manual [20] another relationship to estimate the deformation of the beaches in the vicinity of the groyne has been expressed:

$$Y=\varphi'\sqrt{\frac{4at}{\pi}}(e^{-u^2}-u\theta\sqrt{\pi}). \quad (8)$$

In Eq. (8), variable a, u and θ are obtained from the following relations:

$$a=\frac{Q}{\varphi' d}, \quad (9)$$

$$u=\frac{-x}{\sqrt{4at}}, \quad (10)$$

$$\theta=\frac{2}{\sqrt{\pi}}\int_u^{\infty}e^{-u^2}\mathrm{d}u=1-\frac{2}{\sqrt{\pi}}\int_0^u e^{-u^2}\mathrm{d}u. \quad (11)$$

In above equations; $Q\left(\frac{m^3}{s}\right)$ is discharge along the coast, d(m) is the water depth at the toe of groyne, x(m) is groyne spacing and t(s) is time.

A very important step in solving Eq. (8) is attention to relationship between ϕ and $\frac{\partial y}{\partial x}$, indicates that the wave angle with beach deformation is changed. According to Fig. 16 we have:

$$\phi=\varphi'-\frac{\partial y}{\partial x}\rightarrow\phi'=\phi+\frac{\partial y}{\partial x}. \quad (12)$$

If $Q=0$, the result is that if the wave is perpendicular to the shore, there isn't long shore sediment transport. In fact, at the sediments contact point and groyne assuming the same angle of wave in boundary conditions will result in:

$$X=0:\frac{\partial y}{\partial x}=\phi' \ \text{for}\cdot all\cdot t. \quad (13)$$

From the above description we find that the shape of the coast behind the groyne will follow the pattern of the wave. Beach deformation after different time is shown in Fig. 16.

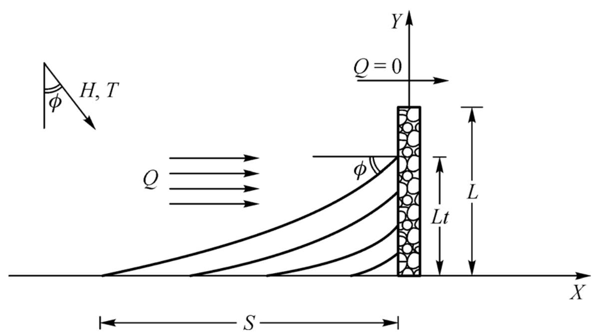

Fig. 16 Beach deformation behind groyns

4 Field investigation

The field measurement was carried out at a location at Dahane Sar sefidrood coast where there was a straight groyne with 100 m length. Beach deformation in the vicinity of the constructed groyne was measured over a period of 15 months; the view of the groyne can be seen in Fig. 17. The updated shorelines, obtained from filed study, empirical equations and proposed model, are given in Fig. 18.

5 Shoreline deformation prediction resulting from the mathematical model

Based on the mathematical model described in the previous section, in this section, a computer program using MATLAB software to simulate the deformation of the long shoreline in the vicinity of the groyne has been

Fig. 17 Beach deformation in the vicinity of groyne at Dahane Sar Sefidrood

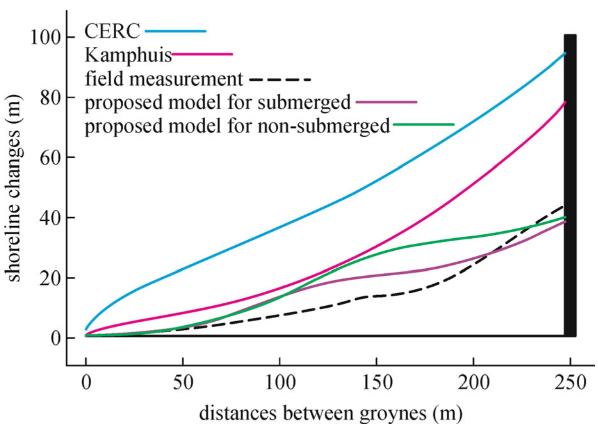

Fig. 18 comparison of updated shorelines in the vicinity of groyne and discussions

performed. The beach deformation is obtained according to equation and net long shore sediment transport rate, is obtained by CERC and Kamphuis formulae and compared with the proposed model in the vicinity of submerged and non-submerged groynes. Also, the results of sediment discharge were presented in Table 1 the approximate equations. The results indicate that if the groyn crest is above the water surface, waves will be greater height at the offshore; the reason for this phenomenon is reflected waves. Also, the studies can be found that reflection phenomenon has not changed with Increase or decrease the crest height of the submerged groin. Wave height for non-submerged groyn is lower than submerged groyn in the on shore and then sediment accumulation in the non-submerged groyn will be greater. The results of predicted beach deformation show that when submerged groyne construct in the beach, sediment accumulation will be slightly less than the non-submerged groyne; because transfer coefficient for the submerged groyne is more than non-submerged groyne. This result will cause more sediment passing on submerged groyne.

6 Conclusions

1) Measurements of beach deformation have been over a period of 15 months for a groyne in the dahane Sar sefidrood which is consistent with the results of the proposed model for almost, the same duration.

2) The proposed model, with acceptable precision can predict the beach morphology and deformation in vicinity of submerged groyne.

3) In this study, analysis of the transmission coefficient for four groynes with various crests was performed and observed that the wave transmission coefficient for the submerged groyne is higher than other cases. The results indicate that the submerged height to wave height on the wave transmission coefficient has a direct effect. Dimensionless parameter crest width to wave height has a direct effect on transmission coefficient. When the wave steepness increases, the wave transmission coefficient decreases. Wave steepness parameter for the submerged groyne was higher than non-submerged groyne. The results of predicted beach deformation show that when submerged groyne construct in the beach, sediment accumulation will be slightly less than the non-submerged groyne; because transfer coefficient for the submerged groyne is more than non-submerged groyne. This result will cause more sediment passing on submerged groyne.

4) Improving the accuracy of the proposed model is recommended in such a way that the beach morphology at each stage, behind the groyn is updated so that calculation the new angle of wave can be considered in the mathematical model.

5) Finally, the result of the present study show that using submerged groyne can be efficient for controlling the sediment and beach erosion without causing severe environmental impact. The important outcome from this study may be employed in optimum design of groyne systems in marine projects.

Table 1 Calculated discharge from approximate equations in the study area

discharge $\left(\frac{m^3}{yr}\right)$	used the approximate relations	row
30763368	Q_{CERC}	1
11941288	Q_{Kamphuis}	2

References

1. Hanson H, Kraus N C. Comparison of shoreline change with physical and numerical models. In: Proceedings of Coastal Sediment. 1991, 1785–1799
2. Badiei P, Kamphuis J W. Physical and numerical study of wave induced currents in wave basin of various. Coastal Dynamics ’95. ASCE, Gdansk, 1995, 377–388
3. Gungordu O, Otay E N. Numerical Model of Shore Change. In: Advances on Civil Engineering 3th Technical Congress. METU, Ankara, Turkey, 1997, 701–710
4. Leont’yev I O. Modeling of morphological changes due to coastal structures. Coastal Engineering, 1999, 38(3): 143–166
5. Özölçer I H, Komurcu M I, Birben A R, Yuksek O, Karasu S. Effects of T-shape groin parameters on beach accretion. Ocean Engineering, 2006, 33(3–4): 382–403
6. Gunaratne G L, Tanaka N, Amarasekara G P, Priyadarshana T, Manatunge J. Impact of rubble mound groyne structural interventions in restoration of Koggala Lagoon, Sri Lanka; numerical modeling approach. Journal of Coastal Conservation, 2011, 15: 113
7. Lashteh Neshaei M A, Afsoos Biria H. Impact of Groyne Construction on Beach; Case Study Anzali & Astara Coasts. In: Proceedings of the 7th National Congress on Civil Engineering. University of Sistan and Baluchestan, Zahedan, Iran, 7–8 May, 2013
8. Lashteh Neshaei M A, Afsoos Biria H, Abbas Taheri A. The pattern of sedimentation in the vicinity of the groyne to the mathematical model Mike 21(Case study: Dahane sar sefid rood). In: Proceedings of the 7th National Congress on Civil Engineering. University of Sistan and Baluchestan, Zahedan, Iran, 7–8 May, 2013
9. General Directorate of Coast and Port Engineering. Iranian Sea Wave Modeling (ISWM), Vol. 2, Caspian Sea. Iran Port and Maritime Organization, 2003
10. Hydrography information of Iranian surveying institute in Dahane Sar Sefidrood. 1991–2010
11. Site, https://maps.google.com/Kiashahr, Gilan, Iran
12. U S Army Coastal Engineering Research Center. Shore Protection Manual. Vols. 1 and 2, Department of the Army, Corps of Engineers, U S Gov Printing Office, Washington D C, USA, 2006
13. Kamphuis J W. Alongshore Sediment Transport Rate. Journal of Waterway, Port, Coastal, and Ocean Engineering, 1991, 117(6): 624–640
14. Seelig W N. Two Dimensional Tests of Wave Transmission and Reflection Characteristics of Laboratory Breakwaters. Technical, report, CERC, Fort Belvoir, 1980, Report n.80–1
15. Powell K A, Allsop N W H. Low-crested breakwaters, hydraulic performance and stability. Technical report, HR Wallingford, 1985, Report SR57
16. Daemrich K, Kahle W. Schutzwirkung von Unterwasser Wellen brechern unter dem Einfluss unregelmassiger seegangswellen. Technical report, Franzius Instituts fur Wasserbau und Kusteningenieurswesen, 1985, Report Heft 61
17. Ahrens J P. Characteristics of Reef Breakwaters. Technical Report, CERC, Vicksburg, 1987, Report Cerc-87–17
18. D’Angremond K, Van der Meer J W, De Jong R J. Wave transmission at low-crested structures. In: Proceedings of the 25th International Conference on Coastal Engineering. ASCE, 1996, 2418–2427
19. Pelnard & Considere, R. Essai de theoti de I’tvolution des forms de ravage en plages de sables et de galets. Societe Hydro technique de France, IVerne Joumtes de L’Hydraulique, Question III, rapport I, 1956, 289–298
20. Shore Protection Manual. Coastal engineering research center, U S Army Corps of Engineering, Washington D C, USA, 1992