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# An Analytical Study on the Formation of Submerged Bars in the Southern Coasts of Caspian Sea

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## ABSTRACT

Measuring cross-shore profiles is very important in coastal engineering studies, since the cross-shore profile determines the behavior of the sea in the coastal area and determines the process of depth changes in this region. As a result of waves, cross-shore profiles change, which will vary in stormy waves (erosion profile) in compare to normal wave conditions (cumulative profile). Considering the great changes in the Caspian Sea level, the purposes of this study are to investigate and determine the erosion or accumulation of coastal profiles based on Sunamura and Horikawa's studies , determine the number of bars in profiles by Short and Aagaard's equations and also determine the relations between coastal parameters with the wave steepness and changes in water level. The results show that for all the coastal areas in the Caspian Sea, the C-parameter is above 8; in other word a stormy erosional nature is dominant. Also according to $B_0$ -parameter, for all regions the values are above 100 which means a very high possibility to form multi bars profiles (three bars) very high. As the wave's steepness rises, the location of the formation of the bars moves toward the coast, and the depth of water decreases at the beginning and the ends of the bars; also, in terms of lowering in the water level with the change in the height of the waves, the position and the geometric shape of the bars will not follow a certain trend

## 1. Introduction

Cross-shore profiles of sandy beaches have a crucial role in design different kinds of port of areas , because the cross-shore profiles will determine the sea's behavior in the coastal zone and will indicate the process of depth changes in this range. As a result of waves, cross-shore change, which will vary in stormy waves compared with the sea normal waves. Storm driven Profiles are called erosion profiles, and while normal wave driven profile are called cumulative profiles. Overview of seasonal changes for the bed profile can be used to design marine structures such as docks, coastal walls and sea-bed pipes that cross the coastal area, as well as to create coastal boundaries and design coastal recovery projects.

In the past, many researchers have done studies on the modeling of cross-shore profiles and cross-shore sediment transport, in order to determine the parameters of storm profiles. Watanable *et al.* (1986) used a three-dimensional model to estimate the amount of cross-shore sediment transport. The results of this three-dimensional model in compare with the formula derived from the transfer of sediments due to the wave and current show that they are in agreement with each other [1]. Larson and Kraus(1989) studied erosion and cumulative profiles and introduced the best criteria for determining the profile of transverse profiles; then geometric parameters of storm profile were calculated using laboratory data and nonlinear regression analysis between geometric characteristics And the characteristics of the wave and sediments [2]. Pruszak *et al.* (1997) examined 81 cross-shore multi bar profile with average slope on the coast of Poland between 1964 and 1994. They calculate and compare the correlation coefficients between two different parameters for each bar and the correlation coefficients between the same parameters for different bars. The results show that the correlation coefficient between the same parameters in different bars decreases with increasing in distance from the coastline, and also by increasing in the height of the bars, the depth of water on the bars will increase [3]. Hsu and silvester (1997) in their studies, coastal profile parameters were determined using experiments and nonlinear regression method. They considered these waves steepness ( $\frac{H_0}{L_0}$ ) and bed slopes (m) as factors influencing the geometric parameters of storm profiles [4]. Hsu (1998) conducted laboratory studies to determine the geometric parameters of a stormy profile. In his experiments, he considered two slopes of the bed and two angles of attack and several different waves steepness. Using the nonlinear regression analysis and the parameter ξ, which determines the relationship between the slope of the bed and the wave velocity, empirical equations to determine Geometric features are considered [5]. Rozynski (2003) explores the bed changes on the coasts of Poland, where they have a gentle slope, dominant wave, multi bars and have no tide. In his study, he used experimental orthogonal functions (EOF) and focal correlation methods (CCA) and by interacting and connecting the results of these two evaluations to a physical model, he describes phenomena and processes [6]. Gunaydin and Kabdasli (2003) conducted laboratory studies to determine the parameters of coastal erosion. By linear regression of the parameters, they provided an empirical relation for each wave state, and by comparing their correlation coefficient they found out that the wave's status is ineffective in determining the parameters of coastal erosion [7]. Hashemi *et al.* (2010) conducted studies in the area of forecasting seasonal changes in coastal profiles; They collected data by examining 19 stations on the coast of the Gulf of Tremodoc, for seven years, such as minimum wind speed, wind direction, number of consecutive winds, number of all winds data, significant wave height, wave period characteristic, wave direction, coastal angle and storm duration and by ANN's (artificial neural network), they predict coastal seasonal variations. The results show that the artificial neural network method is more accurate than other expensive numerical models [8]. Demirci *et al.* (2011) studied sediment transport and the influence of parameters affecting sediment transport during 64 experiments in their studies. In these experiments, the slope of the bed, the average particle size and the wave period were considered as the variables. Based on proposed equation, any increasing in wave steepness ( $H_0/L_0$ ), lead to more sediment transport, which results in the size and volume of the bars. Also they found that, with increasing sediment transfer to the sea, the amount of erosion of sediments increases from the front of the beach (coastal forehead) and the distance between the coastline and the end of the bar increases. They also discovered that the movement of sediments toward the sea leads to the movement of the bars and hence the place of wave break is also displaced [9]. Kömürcü et al. (2013) provided 80 experiments using the Neural Network (NN) to provide equations for determining the geometric characteristics of the stack. Finally, comparing these results with the regression analysis results, showed that the relations obtained from the neural network are in good agreement with experimental results [10]. Uzlu *et al.* (2014) estimate the bar parameters by conducting the experiment on 31 coastal profiles by nonlinear regression, using TLBO and ABC algorithms to optimize the regression equation coefficients. According to the results, the TLBO algorithm shows better results than ABC [11]. Demirci *et al.* (2015) used artificial neural network model (ANN) and multiple linear regression (MLR) to predict the bar volume. They estimate the errors in these two methods and compare them and conclude that ANN provides a better and more accurate estimate for bar size estimation [12]. Cheng *et al.* (2016) carried out studies on 165 beaches and used two Unibest-TC and S beach coastal profile software to estimate storm coastal changes. They argued that the unibest-TC model could be used to determine the direction of the motion of the sandy bars and the S Beach model can be efficient in determining the exact extent of coastal bars erosion as well as shore line changes [13].

Lopez *et al.* (2017) used an artificial neural network model (ANN) to predict the bar parameters formed in the profile. in order to evaluate the performance of the model obtained from the ANN, errors such as absolute error and average relative error and relative error were used, which by comparing these values with the values obtained from previous relations, they realized low errors in the ANN model [14]. Kankal et al. (2018) examined the cross-shore sediment transport by a coefficient that determines the velocity to the equilibrium of sedimentary deposits. They used laboratory data and artificial neural network models to obtain this coefficient. Also, they used two optimization algorithms TLBO and ABC to optimize these models. Finally, the results showed that TLBO-ANN and ABC-ANN had more accurate results than BP-ANN [15]. Lopez et al. (2018) studied cross-sectional profiles of the western shores of the Mediterranean Sea using artificial neural networks to model cross-sectional profiles. In their studies, they considered the effects of marine plants, in addition to the common parameters that other researchers considered. They also compared the results obtained from the neural network with the results obtained from Religion Formulas (1991) and Aragones (2017), and they found a better performance of the model [16].Ataei et al. (2016) carried out studies on some parts of the southern coast of the Caspian Sea, based on measured data as well as the presented equations. The results of this study show that the Caspian Sea coasts are categorized as stormy type [17]. In addition to the relations found by Ataei *et al.* (2016), Sunamura and

Horikawa (1974), carried out studies on the transfer of sediments and parameters affecting cross-shore profiles, provided the parameter $C$ for the classification of coastal profiles. In this equation, $H_0$, $L_0$, $\tan\beta$ and $d_{50}$ are the significant wave height, wave length, bed slope and average particle size respectively[18].

$$C = \frac{H_0}{L_0}(\tan\beta)^{0.27}(\frac{d_{50}}{L_0})^{-0.67} \quad (1)$$

the purposes of this study are to investigate and determine the erosion or accumulation of coastal profiles, determine the number of bars in profiles, and also determine the relations between coastal parameters with the wave steepness and changes in water level.

## 2.Study Area

The Caspian Sea is the largest lake in the world that is not associated with free waters; in recent decades, it has been connected to the Black Sea through the Volga River and the creation of the Volga Channel by Russia. The main source of water entering the Caspian Sea is the Volga River, which accounts for about 80% of the water entering the Caspian Sea. The highest depth of the Caspian Sea is about 1025 meters, and in general the deepest areas of the sea are close to the coast of Iran; the average level of the Caspian Sea water level is 27 meters below the free water level (Shahini, 2006) [19]. In order to investigate the cross-section profiles of the southern coast, necessary information were collected from Anzali and Dastak coastal regions in Gilan province, Namakabrood, Mahmudabad and larim in Mazandaran province and also from Miankaleh in Golestan. The cross-shore profile of the Caspian Sea coastal line is shown in Fig. 1.


**Figure 1. Cross-shore profiles studied for the Caspian Sea coastal line.**

## 3.Methods

Based on parameter $C$, the type of cross-shore profile can be determined such that if $C < 4$ is the cumulative coastal profile (summer), if $4 < C < 8$ is the equilibrium coastal profile and if $C > 8$ is the coastal profile of the erosion type (winter).

According to the relations provided by Short and Aagaard (1993), the number of bar in the coastal profiles can be found. Based on this, Eq. (2) presents the parameter $B_0$ for determining the number of bars and $X_s$ and $T$ are respectively the horizontal distance for the closure depth to the coastline and period of wave. In such a way that if $B_0 < 20$ the profile does not have any bar and the profile is a balance one. If $20 < B_0 < 50$ the profile has one bar, $50 < B_0 < 100$ has two bars, $100 < B_0 < 400$ has a three-bar profile, and if $B_0 > 400$, then the profile will have four bars [20].

$$B_0 = \frac{X_s}{gT^2 \tan\beta} \quad (2)$$

Beach slopes, sediment transport, sea bed, and sea level changes are among the factors affecting cross-shore profiles; In this study, the effect of effective parameters on cross-shore profile deformation has also been evaluated. Fig. 2 shows each of the geometric parameters of coastal profiles.

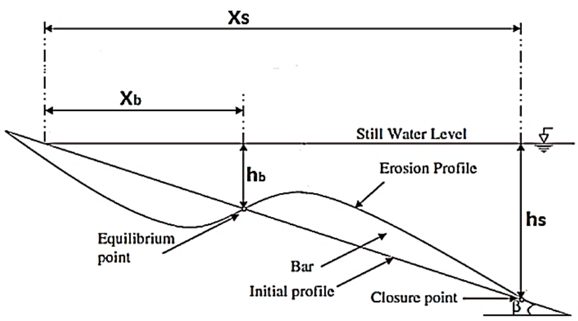
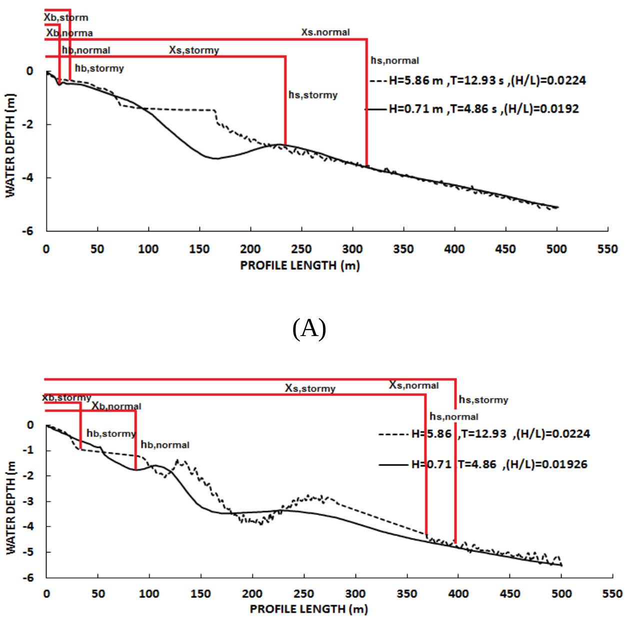



**Figure 2. Geometric Parameters of Coastal Profiles (Kömürcü et al. ,2013).**

## 4. Data Analyses and Discussion

Due to the analysis and survey of the southern shores of the Caspian Sea ,in Fig. 3, the profiles of the studied regions are shown. Also in Table 1, the measured parameters are for 12 years Caspian Sea modeling statistics by Ports and Maritime Organization and Caspian Sea National Research Center)[1], include the significant stormy and normal waves height ($H_0$), wave length ($L_0$),the significant stormy and normal period of wave ($T$), water level change ($S$), average particle size ($d_{50}$), bed slope ($\tan\beta$), horizontal distance of the starting point for the first bar to the coast line, ($X_b$) the initial depth of the starting point for the first bar to the water surface ($h_b$), the horizontal distance for the end of the last bar to the coastline ($X_s$) and the depth of the end point for the last bar to the water surface ($h_s$) are shown.



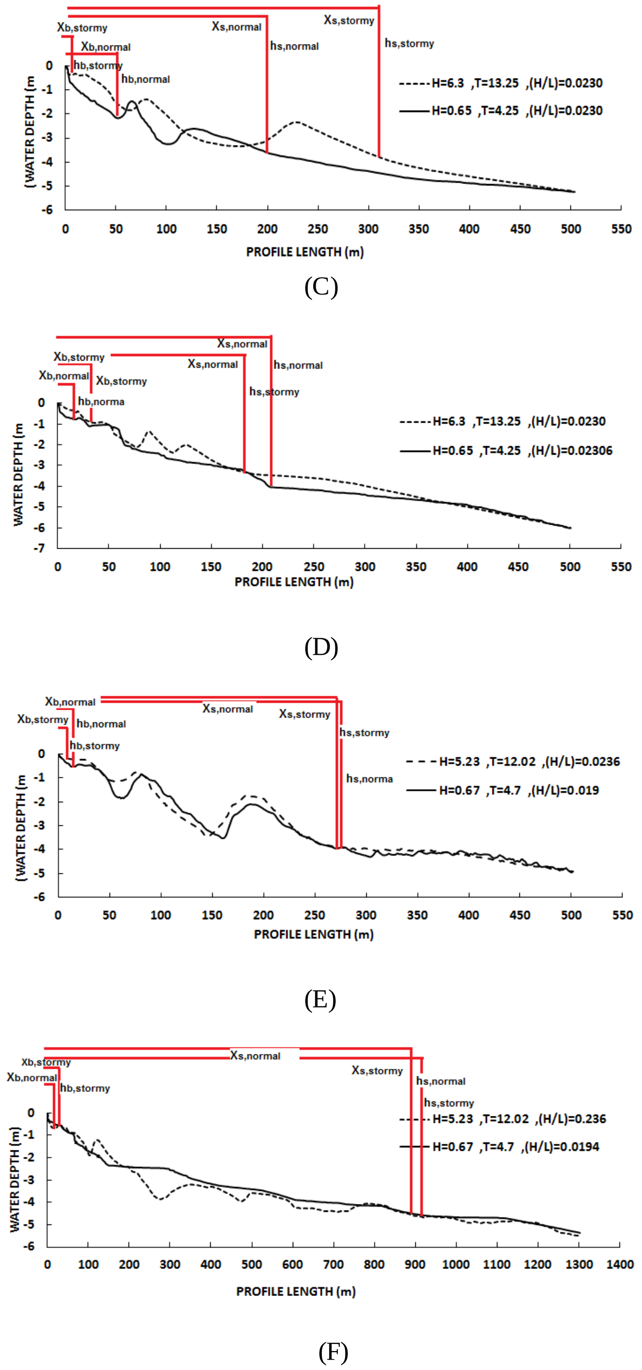




**Figure 3. Profiles of the studied areas; A: Anzali, B: Dastak, C: Namakabrood, D: Mahmudabad, E: Larim, F: Miankaleh (CSNRC Report, 2016 [21]**

[1] Data was taken as a text file (x-z) from the Ports and Maritime Organization and Caspian Sea National Research Center (2016).

**Table 1. Parameters measured from the southern shores of the Caspian Sea (Ataei et al., 2016 [22]; PMO report, 2016 [23]).**

| Parameters | Anzali | Dastak | Namakabrood | Mahmudabad | Larim | Miankaleh |
|---|---|---|---|---|---|---|
| $H_{0\max}$ *(m)* | 5.86 | 5.86 | 6.3 | 6.3 | 5.32 | 5.32 |
| $L_{0\max}$ *(m)* | 260.81 | 260.81 | 273.88 | 273.88 | 225.39 | 225.39 |
| $T_{\max}$ *(sec)* | 12.93 | 12.93 | 13.25 | 13.25 | 12.02 | 12.02 |
| $H_{0mean}$ *(m)* | 0.71 | 0.71 | 0.65 | 0.65 | 0.67 | 0.67 |
| $L_{0mean}$ *(m)* | 36.85 | 36.85 | 28.18 | 28.18 | 34.46 | 34.46 |
| $T_{mean}$ *(sec)* | 4.86 | 4.86 | 4.25 | 4.25 | 4.7 | 4.7 |
| $x_s$ $(m)$ | 454.43 | 451.04 | 327.85 | 296.80 | 454.85 | 885.36 |
| *S (m)* | -0.132 | -0.132 | -0.132 | -0.132 | -0.132 | -0.132 |
| $D_{50}$ *(m)* | 0.0002 | 0.00019 | 0.00023 | 0.00019 | 0.00017 | 0.00017 |
| $\tan\beta$ | 0.011 | 0.011 | 0.013 | 0.015 | 0.010 | 0.005 |
| $X_{s_{Stormy}}$ *(m)* | 252.82 | 369.17 | 318.54 | 178.67 | 278.88 | 891.57 |
| $X_{s_{Normal}}$ *(m)* | 315.42 | 393.00 | 198.45 | 211.77 | 254.74 | 891.34 |
| $X_{bStormy}$ *(m)* | 46.68 | 31.75 | 6.88 | 27.67 | 66.65 | 48.38 |
| $X_{bNormal}$ *(m)* | 33.48 | 89.70 | 53.40 | 16.08 | 16.17 | 17.35 |
| $h_{bStormy}$ *(m)* | 0.26 | 0.88 | 0.38 | 0.43 | 1.16 | 0.56 |
| $h_{b_{Normal}}$ *(m)* | 0.5 | 1.75 | 2.16 | 0.75 | 0.53 | 0.70 |
| $h_{sStormy}$ *(m)* | 2.97 | 3.96 | 4.30 | 3.14 | 3.89 | 4.59 |
| $h_{s_{Normal}}$ *(m)* | 3.43 | 4.75 | 3.35 | 4.05 | 3.77 | 4.56 |

Based on the Eqs (1) and (2), the performance of the coastal areas of the Caspian Sea has been studied and analyzed based on the cumulative, equilibrium and coastal erosion category and the number of bars. The results are presented in Table 2.

**Table 2. Calculating parameter C and determining the number of the Caspian Sea bars.**

| Parameters | Anzali | Dastak | Namakabrood | Mahmudabad | Larim | Miankaleh |
|---|---|---|---|---|---|---|
| $C$ | 19.22 | 19.89 | 18.32 | 21.64 | 20.15 | 16.71 |
| Type of the cross shore profiles | erosion profile | erosion profile | erosion profile | erosion profile | erosion profile | erosion profile |
| $B_0$ | 177.6 | 176.3 | 141.7 | 111.2 | 208.2 | 810.5 |
| Number of the bars | 3 | 3 | 3 | 3 | 3 | 4 |

As shown in the calculations, the parameter $C$ in the areas determined on the Caspian Sea coast is always greater than 8 and has values between 16 and 22, so it can be stated that the Caspian Sea behavior has a stormy nature and the coast has erosional nature.According to Table 2, the beach profiles for Dastak, Namakabrood, Mahmudabad and Larim have three bars and the profile of the Miankaleh coastline has four bars. The Anzali cross-shore profile has three bars, according to Eq. (2), but as seen in field data, it has two bars. The reason is the proximity of the location of collection Anzali profiles data to the port, which affects coastal interactions.

To facilitate the use of field data and reduce the error rate $X_b$, $X_s$, $h_b$, $h_s$ and $H_0$ parameters are converted to dimensionless numbers relative to the wave length, and the change in the water level. In Figs. 4 and 5, the relation between the wave steepness and the dimensionless ratio of the geometric parameters of the profiles and the relation between $H_0/S$ and the dimensionless ratio of the geometric parameters in a situation where the change in water level in all regions are the same is evaluated.

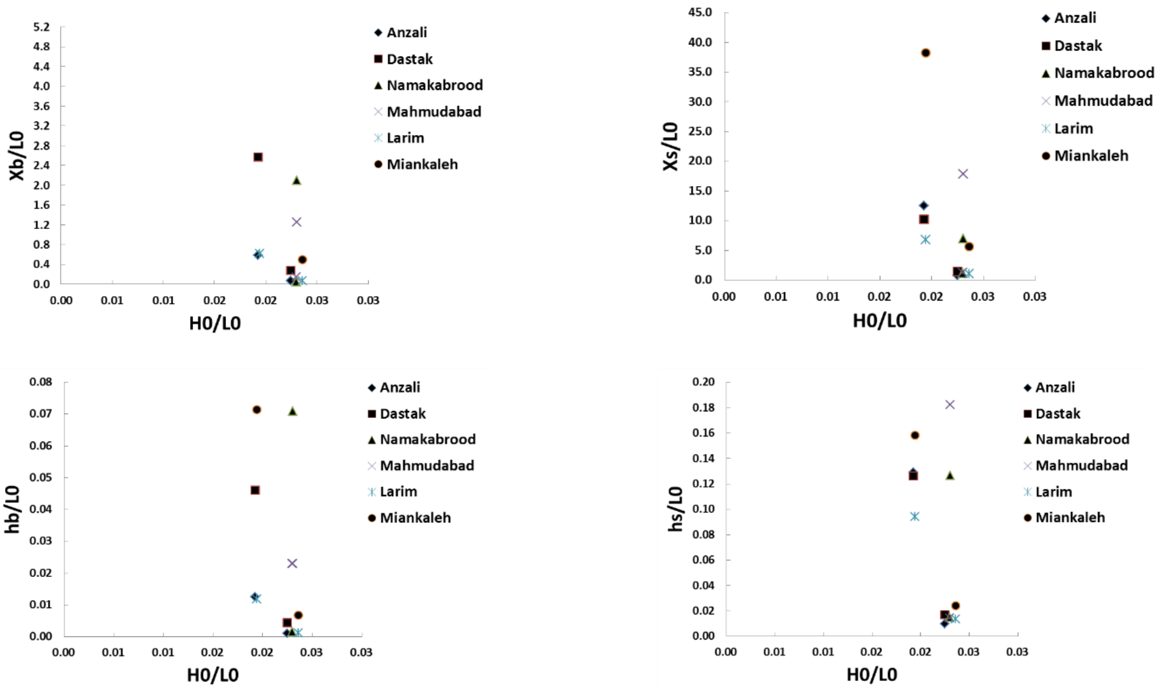



**Figure 4. Comparison of the dimensionless parameters of coastal profile with the wave steepness ratio**.

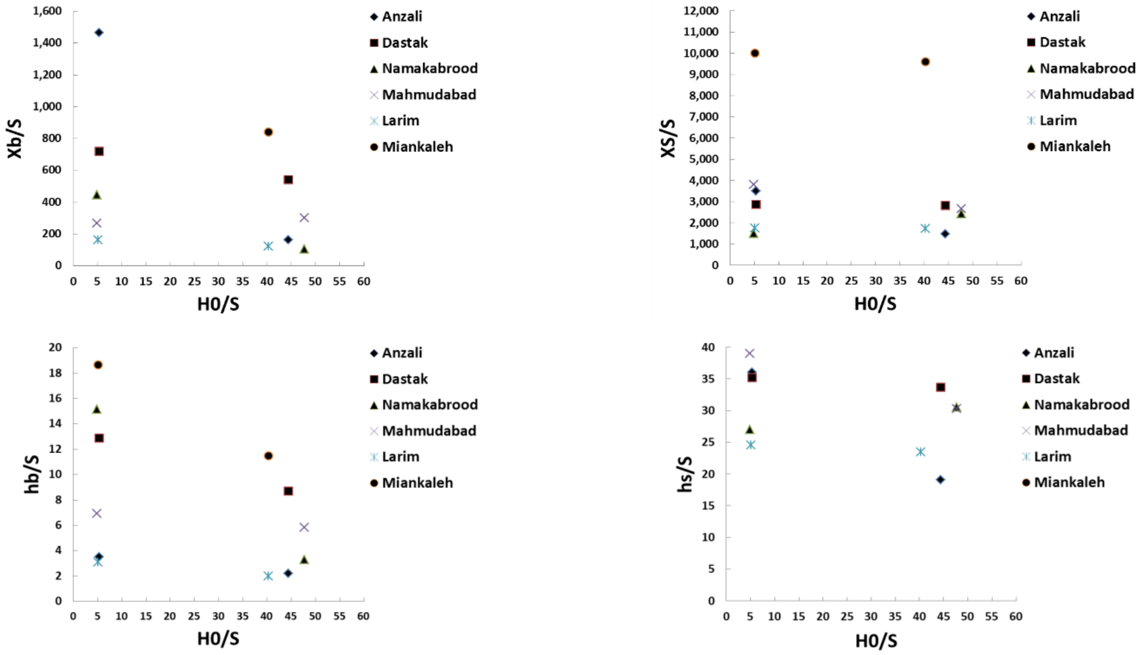



**Figure 5. Comparison of the dimensionless parameters of the coastal profile with the $H_0/S$ ratio.**

As shown in Fig. 4, with increase in the wave steepness ($H_0/L_0$), the ratios of $x_b/L_0$ and $x_s/L_0$ in the most of the profiles are reduced, thus it can be stated that the coastal bars begin to form at a shorter distance from the coastline and the general displacement of the bars happens toward the coast line. Also, the ratios of $h_b/L_0$ and $h_s/L_0$ in most of profiles are also reduced; as these ratios are reduced, the depth of water decreases at the beginning and the end of the bars, which indicates that the erosional beach will be created. King (1972), based on experimental results, modified the location of wave breaking zone due to gradual bars movement, which the results of our studies are consistent with his findings [24].

According to Fig. 5, with constant consideration of water level changes, it is observed that in the conditions of lowering in the water level, by the increase of the wave height, the location of the formation of coastal bars in all regions of the study is not approached to the coast line. As the wave height decreases, the $x_s$ in the coastal profiles of the Larim, Miankaleh, Dastak and Namakabrood areas declines and increases in the coastal profiles of Mahmoudabad and Anzali. Also, with decreasing in wave height, $x_b$ in the Anzali, Mahmudabad and Larim coastal profiles declines and increases in the coastal profiles of the Dastak, Namakabrood and Miankaleh. The geometric parameter of $h_s$ increases with decreasing in wave height in all coastal profiles except Larim and finally for $h_b$, with decreasing in wave height in the coastal profiles of the Dastak, Namakabrood, Larim and Miankaleh decreases and for Anzali and Mahmudabad coastal profiles increases. This suggests the complexity of the sea's environmental conditions in the state of the water level change, since as water level decreases, the interactions of the wave particles with the bed change, and the type of wave break and its distance to the coast line will be affected.

## 5. Conclusion

Measuring cross-shore profiles is very important in coastal engineering studies, since the cross-shore profile determines the behavior of the sea in the coastal area and determines the process of depth changes in this range. The purpose of this study is to investigate the southern shores of the Caspian Sea and determine the erosion or accumulation of coastal profiles, determine the number of bars, and also determine the relation between coastal parameters with the wave's steepness and water level changes.

The *C* parameter in the areas determined on the Caspian Sea coast is always greater than 8 and has values between 16 and 22, so it can be stated that the Caspian Sea behavior has a stormy nature and the coast has erosional nature. The beach profiles for Namakabrood, Mahmudabad and Larim (most of the beach profiles) have three bars and the profile of the Miankaleh coastline has four bars. According to calculations, the Anzali cross-shore profile has three bars, but as seen in field data, it has two bars. The reason for this difference is the proximity of the location of collection Anzali profiles data to the port, which affects coastal interactions.

With increase in the wave steepness, the ratios of $x_b/L_0$ and $x_s/L_0$ in all profiles are reduced, thus it can be stated that the coastal bars begin to form at a shorter distance from the coast line and the general displacement of the bars happens toward the coastline. The ratios of $h_b/L_0$ and $h_s/L_0$ are also reduced; as these ratios are reduced, the depth of water decreases at the beginning and the end of the bars, which indicates that the erosional beach will be created.

With constant consideration of water level changes, it is observed that in the conditions of lowering in the water level, by the increase of the wave height, the location of the formation of coastal bars in all regions of the study is not approached to the coastline. Also, the process of water depth changes at the beginning and end of the bars is not uniform. This indicates the complexity of the sea's environmental conditions in the state of the water level change, since as water level decreases, the interactions of the wave particles with the bed change, and the type of wave break and its distance to the coast line will be affected. The results show that the behavior of the coastal areas of the Caspian Sea is a stormy nature with a coastal erosion, which makes it possible to form multi bars profiles (three bars) very high. As the wave's steepness rises, the location of the formation of the bars moves toward the coast, and the depth of water decreases at the beginning and the ends of the bars; also, in terms of lowering in the water level with the change in the height of the waves, the position and the geometric shape of the bars will not follow a certain trend.

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