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Classification of Barred and Unbarred Beach Profiles in the Caspian Sea

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Abstract: Nearshore bars are common morphological features along many of the world's beaches. Although bars develop as a result of sediment convergence, troughs form due to sediment divergence. Nearshore bars are the most dynamic morphological elements of the surf zone. Offshore sediment transport leads to erosion of the beaches and the formation of barred profiles, whereas onshore sediment transport causes beach accretion and non-barred profiles. The southern coasts of the Caspian Sea are the subject of studies in this research. Considering the probability of cross-shore profiles formation in a period of one year, the related specifications to wave's average were used in order to investigate the Caspian Sea's balanced nature of trends. In most profiles of Dastak, Namakabrood, Mahmoodabad and Larim coasts, three bars have been formed. In addition, in most of Miankaleh's profiles, four bars have been formed. The only contrary trend to the predictions belongs to Anzali's profile, where only two profiles were formed. According to the conducted researches, the southern coasts of the Caspian Sea are categorized as the type of coasts with the possibility of bar formation under normal conditions, although three bars would be formed along most of its coasts.

Keywords: Barred and Unbarred Beach; Cross-Shore Profile; Sediment Transport; Caspian Sea.

1. Introduction

Nearshore bars are common morphological features along many of the world's beaches. They are the main reason of hydrodynamic and sediment transport gradients. Although bars develop as a result of sediment convergence, troughs form due to sediment divergence. Nearshore bars are the most dynamic morphological elements of the surf zone, and hence they are a major topic in coastal researches.

Long-term monitoring of beaches on the West coast of the United States led to the identification of 'winter' and 'summer' profiles and seasonal cycle of beach morphology [1, 2]. Winter storms result in the removal of sand from the berm and the formation of a breakpoint bar, while calmer weather conditions in the summer induce landward migration of the bar and consequently, joining of the bar to the beach face and the generation of a non-barred cross-shore profile with a wide berm [3].

Recent studies indicate that the terms 'winter' and 'summer' are somehow misleading and only demonstrate the cyclic of beach response, as opposed to its seasonal behavior, and they may only result in several cycles of barred or non-barred profiles within a year which depend on the weather storm and wave conditions [4].

The separation between barred and non-barred profile is generally related to the direction of cross-shore sediment transport. Offshore sediment transport leads to erosion of the beaches and the formation of barred profiles, whereas onshore sediment transport causes beach accretion and non-barred profiles (Figure 1). However, once a certain nearshore morphology has been developed and the prevailing hydrodynamics conditions remained relatively constant, the morphology can be maintained under conditions of no net sediment transport.

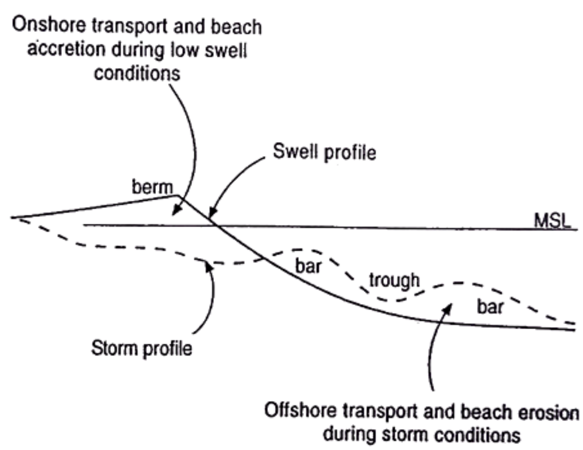

Figure 1. Idealized barred and non-barred beach profiles [5].

When beach profile changes at one location are considered, the wave height seems to be relatively effective for distinguishing between barred and non-barred profiles. For the south-east coasts of Australia, for example, Short (1979) found that if the offshore significant wave height exceeds 1.2 *m*, barred profiles are formed, whereas if offshore wave height is smaller than 1.2 *m*, onshore sediment transport and eventually non-barred profiles will appear [6]. However, such conclusions are due to site-specific and some factors such as wave period

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and sediment size and must be included for universal models.

2. Barred and Unbarred Beaches

Small-scale laboratory investigations correlated the cross-shore sediment transport direction and the occurrence of bar morphology with the deep water wave steepness (H_0/L_0). Steep waves ($H_0/L_0 > 0.02$) were found to be the main reason for offshore transport and the formation of a barred profile. Waves with a low steepness ($H_0/L_0 < 0.02$) on the other hand, promote onshore transport and formation of a non-barred profile [7]. The goal of field studies and large-scale laboratory experiments is to find significantly lower threshold values and this discrepancy was primarily dependent on the cross-shore sediment transport direction on the beach and sediment size [8].

Demirci et al. (2011), Demirci and Sami Akoz (2012, 2013) and Demirci et al. (2015) conducted several experiments on a model based on the gradient and median size of different sedimentary particles in a storm conditions. By increasing the depth in the deep water area, increasing the H_0/L_0 ratio and reducing the average diameter of the sedimentary particles, it was observed that the size of the bar and its displacement were increased towards the sea; the width of the bar also increased. By decreasing the coastal slope, the location of the bar will also be directed toward the sea and its width will increase; the sediment transport volume will be reduced as well. They developed the Artificial Neural Network and multi-linear regression models based on the experimental model and effective parameters which showed an acceptable adaptation to the experimental model [9-12].

Based on laboratory experiments and according to equation (1), Gourlay (1980) introduced the dimensionless fall velocity to distinguish between non-barred beaches ($\Omega < 1$) and barred beaches ($\Omega > 1$) [13].

$$\Omega = \frac{H_0}{w_s T} \tag{1}$$

Taaouati et al. (2011) by studying the Charf el Akab beach on the northern coast of Morocco, taking into account low-energy (summer) and high-energy waves (winter or storm waves) and their effect on the transport of sand sediments and the formation of bars, concluded that the Charf el Akab is a beach with the possibility of forming bars and generally one bar could be created by waves [14].

A similar parameter for the dimensionless fall velocity was derived by Sunamura (1984) [15]:

$$K = \frac{H_b^2}{gT^2 D_{50}} \tag{2}$$

Where D_{50} is the median sediment grain size. In the above formula, K by value of 10 separates barred and non-barred beaches, while $K > 10$ results in bar formation [16].

Uzlu et al. (2014) analyzed TLBO and ABC algorithms to estimate the bar parameter by performing multiple laboratory tests and optimizing the bee colony algorithms using regular waves and considering their height and period. Based on their results, the TLBO algorithm has a better match with the experimental model and they suggested it for beach profile studies [17].

Further analysis of large-scale laboratory data and field data led to the formulation of a new profile parameter, P [18]:

$$P = \frac{gH_0^2}{w_s^3 T} \tag{3}$$

For $P > 9000$, barred profiles develop and non-barred profiles are formed when $P < 9000$.

Choi et al. (2016) studied the experimental model of beach profile changes based on the characteristics of two types of waves in the Haeundae Coast of Korea. The simulated beach was placed under normal waves for 120 minutes and then for 60 minutes under stormy conditions; accordingly, in the stormy conditions, the bar appeared in the beach profile and the slope increased in the swash zone, and then under normal conditions, the crest and trough began to disappear. Also, erosion and sedimentation were observed in stormy and normal conditions. Based on the effective parameters applied in the model, according to the Haeundae Coast's environmental conditions, the formation of bars fully matched with the measured profiles [19].

3. Bar Morphologies

Nearshore bar morphology can assume a wide variety of configurations in which the number of bars appear and their shapes may vary considerably. Multi-barred morphology (two to four bars) is primarily found in storm wave dominated sea and lacustrine environments where long periods of low wave energy conditions alternate with short intense storms [20]. The outer bar or bars are only active during storms and can be considered as relict features during periods of lower energy conditions. However, multiple bars (usually two bars) may also be found in environments that consistently experience high energy swell conditions [21].

Multi-barred nearshore morphology exhibits a tendency towards an increasing number of bars with decreasing beach slope [22]. In addition, the bar spacing increases exponentially in the offshore direction. Short and Aagaard (1993) reviewed the literature on multi-barred beaches and introduced a bar parameter (B_*) to predict the number of bars on nearshore profiles that can be approximated by a linear slope $\tan\beta$, terminating at a constant depth at a distance x_s from the shoreline [23]:

$$B_* = \frac{x_s}{gT^2 \tan\beta} \tag{4}$$

On the basis of field data, Short and Aagaard (1993) suggested that no bars occur when $B_* < 20$, one bar occurs for $B_* = 20-50$, two bars for $B_* = 50-100$, three bars for $B_* = 100-400$ and four bars for $B_* > 400$. The formulation of the bar parameter is based on the premise that standing infragravity waves are responsible for bar formation [23].

Wijnberg and Kroon (2002) explained that the sandy coast morphodynamic system is able to express itself with a variety of nearshore bar types. Based on the literature, seven types of bars are distinguished. These different expressions of the nearshore morphodynamic system are associated with differences in boundary conditions concerning wave energy, nearshore slope and tidal range [24].

4. The Southern Coasts of the Caspian Sea

With its natural and regional conditions, the Caspian Sea is one of the best places to conduct coastal engineering studies. A typical Caspian Sea coast is shown in Figure 2.

Figure 2. Caspian Sea Coast in the Anzali Zone.

The southern coasts of the Caspian Sea were studied in this research. Necessary information such as the mean sediment particle size (D_{50}), wave conditions and some other related parameters of the southern coasts are shown in Table 1 from Anzali and Dastak coastal regions in Guilan province, Namakabrood, Mahmoodabad and Larim in Mazandaran province and also for Miankaleh in Golestan province [25]. The southern part of the Caspian Sea and the studied coasts can be seen in Figure 3.

Figure 3. Zones of the study profiles.

5. Analysis and Discussion

With regards to the proposed parameters for recognizing and categorizing the southern coasts of the Caspian Sea and also the information derived from the Caspian Sea according to Table 1, the calculated parameters based on Equations (1) to (4) are illustrated in Table 2. Considering the probability of cross-shore profiles formation in a period of one year (summer profile and winter profile), the related specifications to waves average were used in order to investigate the Caspian Sea's balanced nature of trends.

According to Table 2, Eq. (1) and considering H_0, T and w_s parameters from the studied beaches, the obtained Ω values for all six beaches are more than one; based on this parameter, the beaches of the Caspian Sea are categorized as barred beaches; especially the Miankaleh, Larim, Mahmoodabad and Dastak beaches that their obtained Ω values are more than six. Among the six studied beaches, Namakabrood with the value of 4.9 has the closest value to one but according to the classified range by Gourlay (1980), it will be placed on the class of beaches with bar formation potential [13]. In the parameter defined by Sunamura (1984) which is provided to predict the type of beaches with or without the possibility of bar formation (summer profile), the H_b, T, g and D_{50} are involved [15]. By studying these parameters for the mentioned beaches, the values of *K* are more than 10 for Dastak, Namakabrood, Mahmoodabad, Larim and Miankaleh beaches, especially in the beaches of Miankaleh, Larim and Mahmoodabad, the values of the parameter are more than 11 which indicates the placement of the beaches in the group of beaches with the possibility of bar formation. The *K* value obtained for the Anzali Beach is 9.9, which is very close to 10; therefore, Anzali beach should be considered as a beach without the possibility of bar formation. However, with regard to the values of Ω and P both of which are showing the formation of bars, it is possible to ignore the low error rate of *K* and the reason for this error lies in the location of the Anzali Beach near one of the most sedimentary rivers at the North of Iran (Sefidrood); in the next section, the measured profiles are studied.

Dalrymple (1992) defined *p* parameter to classify the beaches with and without the possibility of bar formation [18]. Based on Eq. (3) and Table 2, it is observed that the values obtained for all beaches are more than 9000, which means that all the southern beaches of Caspian Sea are of the type with the possibility of bar formation. Miankaleh and Larim beaches have the highest values among the ones under study.

Upon investigating the B^* value of the coasts under study, it is inferred that the value of this parameter is between 100 to 400 for coasts of Anzali, Dastak, Namakabrood, Mahmoodabad and Larim, which according to the aforementioned subjects, would observe the formation of three bars. Moreover, the value of this parameter is more than 400 for Miankaleh coast which means that the cross-shore costs of Miankaleh would have more than four bars. The measured profiles of the coasts under study are illustrated in Figure 4.

As can be observed in Figure 4, in most profiles of Dastak, Namakabrood, Mahmoodabad and Larim coasts, three bars have been formed. Also, in most of Miankaleh's profiles, four bars have been formed. The only contrary trend to the predictions belongs to Anzali's profile where only two profiles were formed. One of the factors affecting it is the flow of the Sefidrood River and its sedimentation; these sediments disturb the natural formation of coastal profiles due to waves in Anzali Beach and the number of created bars will differ from the numerical value of the existing equations.

Table 1. Beach characteristics for the southern areas of the Caspian Sea [25, 26].

Parameter/Zone	Anzali	Dastak	Namakabrood	Mahmoodabad	Larim	Miankaleh
D_{50} (*m*)	0.0002	0.00019	0.00023	0.00019	0.00017	0.00017
$H_{0\ mean}$ (*m*)	0.71	0.71	0.65	0.65	0.67	0.67
T_0 (*Sec*)	4.86	4.86	4.25	4.25	4.7	4.7
$H_{B\ mean}$ (*m*)	0.68	0.68	0.65	0.65	0.66	0.66
T_B (*Sec*)	4.87	4.87	4.26	4.26	4.72	4.72
x_s (*m*)	454.437	451.044	327.856	296.805	454.858	885.369
$Tan\beta$	0.011	0.011	0.013	0.015	0.010	0.005
w_s (*m/s*)	0.0257	0.0238	0.0314	0.0238	0.0200	0.0200

Table 2 - Calculated data from Caspian Sea Parameters.

Parameter/Zone	Anzali	Dastak	Namakabrood	Mahmoodabad	Larim	Miankaleh
Ω	5.7	6.1	4.9	6.4	7.1	7.1
K	9.9	10.5	10.3	12.5	11.7	11.7
P	59920	75446	31487	72310	117072	117072
B_*	177.6	176.3	141.7	111.2	208.2	810.5

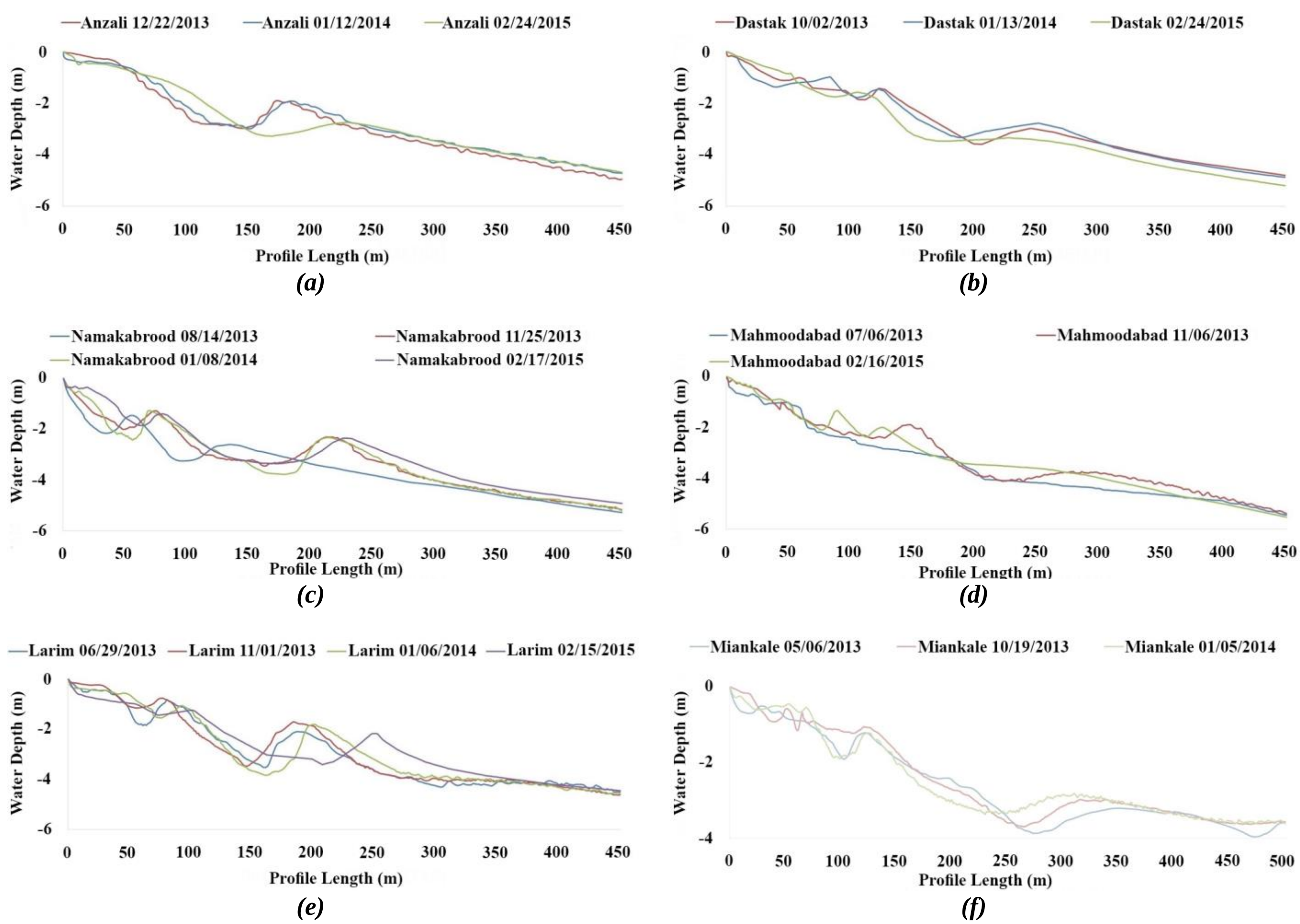

Figure 4. Caspian Sea coasts profiles [27]

6. Conclusion

Tracking the trends in coastal cross-shore profiles is extremely significant for designing seaside environments and coastal resorts, such that by tracking trends in coasts and the number of bars formed during storms as opposed to normal conditions, it would be possible to reduce the risks of designing seaside environments and coastal resorts intended for swimming.

Regarding the investigations done on the existing equations, the cross-shore profiles of the Caspian Sea are of the coastal type with the possibility of bar formation; hence, recognizing the bars and their numbers would be significantly important for risk reduction.

By looking through the related equation to the number of bars formed and also comparing that with the measured cross-shore profiles, it is comprehended that the trends in southern coasts of the Caspian Sea have more conformity with the predictions made based on the existing equations. Based on this, the cross-shore profiles of Dastak, Namakabrood, Mahmoodabad and Larim belong to the type of coast with the possibility of formation of three bars, and cross-shore profile of Miankaleh is of the type of coast with the possibility of formation of four bars. Anzali’s cross-shore profile based on the calculations is categorized as those coasts with the possibility of formation of three bars; but the measured profiles only show the formation of two bars.

Bearing all the investigations in mind, the southern coasts of the Caspian Sea is considered as the type of coast with the possibility of bar formation and under normal conditions, three bars would be formed in most of its coasts.

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