INTERNATIONAL JOURNAL OF
COASTAL & OFFSHORE ENGINEERING
IJCOE Vol.4/No. 3/Fall 2020 (43-48)

An analytical and field study on influence of breakwaters on beach morphological evolution: a case study (Astara Port)

Sahar Javansamadi[1], Ali Karami Khaniki*[2], Abbaas Ali Aliakbar Bidokhti[3], Kamran Lari[4], Majid Ghodsi[5]

[1] Department of Environment, Science and Research Branch, Islamic Azad University, Tehran
*[*2] Soil Conservation and Watershed Management Research Institute (SCWMRI), Tehran*
Akk7239@yahoo.com
[3] Institute of Geophysics, University of Tehran, P.O. Box 14155-6466, Tehran
[4] Department of Marine Science and Technology, Islamic Azad University, Tehran North Branch, Tehran
[5]Department of Environment, Science and Research Branch, Islamic Azad University, Tehran

ARTICLE INFO

Article History:
Received: 23 Aug. 2020
Accepted: 27 Oct. 2020

Keywords:
Morphological evolution
Modified equilibrium profile Astara Port
Sediment transport
Field measurement

ABSTRACT

Addressing the interaction of the presence of coastal structures, breakwaters for instance, and morphological changes is of great importance. The purpose of this paper is to investigate the influences of the extended breakwaters of Astara Port on sediment transport and beach morphological evolution in the vicinity of them so as to identify how the extension of breakwaters altered the sea bed topography. In order to describe evolving cross-shore profiles in the study area, beach profile surveys were conducted by a single-beam echo sounder. Results showed that the breakwaters considerably affected their surroundings, and scouring in front of them was obvious. Furthermore, comparisons of measured beach profiles with Dean's profile model for the equilibrium beach profile illustrated that the Dean's profile was not able to precisely represent the time- mean profiles. As a result, Dean's equilibrium profile was modified and a new model was developed so that it can represent more correctly cross-shore morphodynamics of the study area. The results revealed that modified equilibrium profile can be a better representative for the cross-shore profiles of the study area.

1.Introduction

Coastal protection engineering works, such as breakwaters, influencing waves, wave-induced nearshore currents, and sediment transport, are carried out so as to protect coasts or harbors against the effects of waves and longshore drift (Tang et al. 2017; Kristensen et al. 2013). The structures can affect bottom topography and the shoreline contour, resulting in overall and local deformations that would not evolve without the presence of them. Overall deformations can cause morphological evolution owing to the disturbance of longshore sediment movement, and the second ones can bring about changes in movements of sediments in the vicinity of the coastal structures during a given storm event (Jackson et al. 2015; Leont'yev 1999; Dolphin et al., 2005). Thus, gaining a deep understanding of changes is of great practical interest and importance (Nam et al. 2011; Leont'yev 1999; Turker and Kabdaşlı 2006).

Numerous investigations have been carried out to evaluate the effects of coastal structures on beach morphologies. Jackson et al. (2015) identified how breakwaters with different layout alter asymmetry of the salient. Basco et al. (1992) investigated beach profile change due to the presence of seawalls installed at Sandbridge so as to protect the land. Based on 14 years of data, they found that the berm lowering rate was marginally larger at seawalled sections in comparison to dune/beach sections. Also, they didn't find any convincing evidence to prove the claim that seawalls had caused higher shoreline recession rates in the study area.However, measuring changes in underlying bathymetry is so expensive that numerous reliable numerical models have been developed to simulate morphological changes. As a result, many numerical studies have been performed to understand the morphological evolution around coastal structures. Since waves, wave-induced nearshore currents have decisive effects on sediment transport, these studies have placed considerable importance on correctly modelling waves and wave-induced nearshore currents. The results obtained from this approach look encouraging (Broker et al., 1995; Roelvink et al., 1995, Nicholson et al., 1997; Leont'yev, 1999; Zyserman and Johnson, 2002; Johnson, 2004; Saied and Tsanis, 2005; Birben et al., 2007; Du et al., 2010; Ranasinghe et al., 2010; Nam et al. 2011; Tang et al. 2017).Furthermore, an understanding of equilibrium beach profiles may be useful in some problems of coastal engineering (Dean 1991). Using equilibrium beach profiles, which approximately demonstrate the important features of cross-shore profiles a beach, the response of beach profiles under changing hydrodynamic conditions can be shown (Holman et al. 2014; Türker and Kabdaşlı 2006). In addition, this proxy can be particularly used for cases of unknown or poorly known bathymetry and also for evaluation of long-term sediment volume response to sea level rise (Özkan-Haller and Brundidge, 2007, Holman et al. 2014). The best known and most commonly used equilibrium beach profile form is Dean's profile, which determines the shape of equilibrium beach profile with regard to the offshore distance and the sediment. The profile does not consider the effects of wave climate, and coastal currents (Dean 1991; Türker and Kabdaşlı 2006; Gonzalez et al. 1999). Several equilibrium beach profiles have been characterized to represent cross-shore profiles subject to different conditions (Dean 1991, Özkan-Haller and Brundidge, 2007, Bodge 1992; Holman et al. 2014).Beach profiles are likely to stay the same under long-term wave climate and persistent sediment size, which means that the sediment transport is equal to zero (Bowen 1980). Bruun (1954) proposed the power law approach, most used form of equilibrium beach profile, but it is commonly known as Dean's profile. It can mathematically define the shape of equilibrium beach profile:

$$h = Ax^{2/3}$$

Where h is water depth, x is seaward distance from the shoreline and A is the sediment-dependent scale parameter (Dean 1991).

2.Study Area

Astara port (38.4069 °N and 48.8815°E) is located at the southwestern section of the Caspian Sea, Iran (Figure 1) The port is bounded to the east by the Caspian Sea, to the north partially by Azerbaijan Republic, to the south by Guilan Province, and to the west by Ardabil Province. In 1996, Astara port was mainly built as a port for fishing, trading, and travelling. After the extinction of Kilka fish, the fishery activities of the port have been stopped. Due to the positive effects the port had on the development of the region, it has been enlarged. As a result, the northern breakwater with a length of 470 m and the southern breakwater with a length of 187 m have been built (Figure 2).

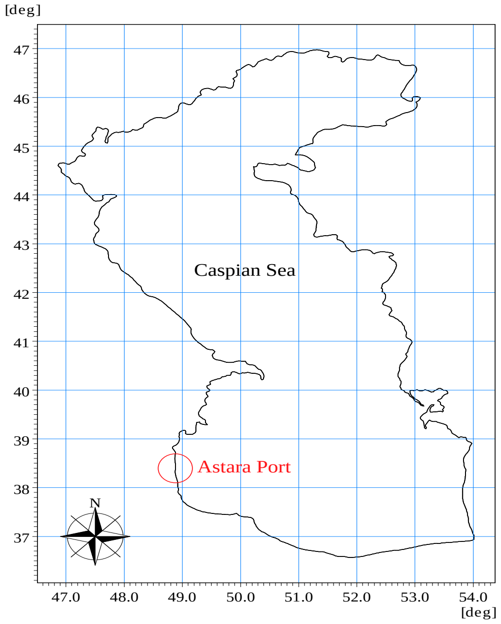


Figure 1. Location of Astara Port

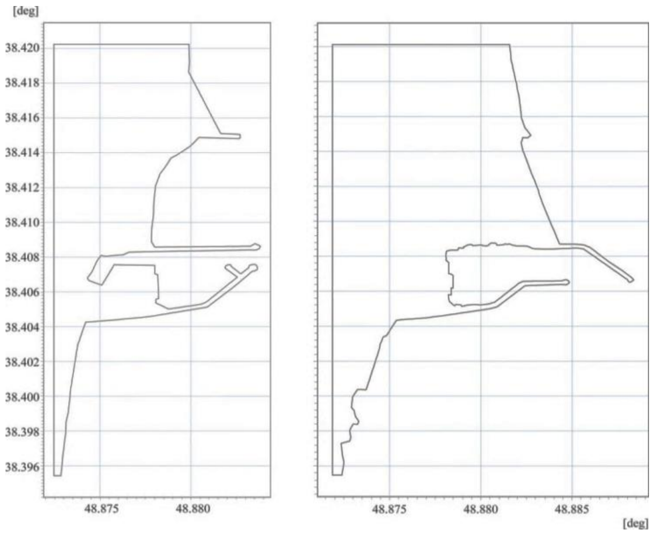


Figure 2. The layout of breakwaters constructed at Astara Port before (left) and after redevelopment (right)

The area under study is exposed to Mediterranean climate with warm summers, moderate and rainy winters. The annual prevailing winds in the area are northerly, northwesterly, and northeasterly. The water level of the port, like that of the Caspian Sea, is currently around 27 m below the level of world oceans. Since there are no tides in the Caspian Sea (Ranjbar and Hadjizadeh 2018; Beni et al. 2013), the tidal water-level fluctuations are negligible in the port. Wave rose for study site shows that the prevailing wave direction is from the north-east. In addition, the dominating current direction is southward (Figure 3).

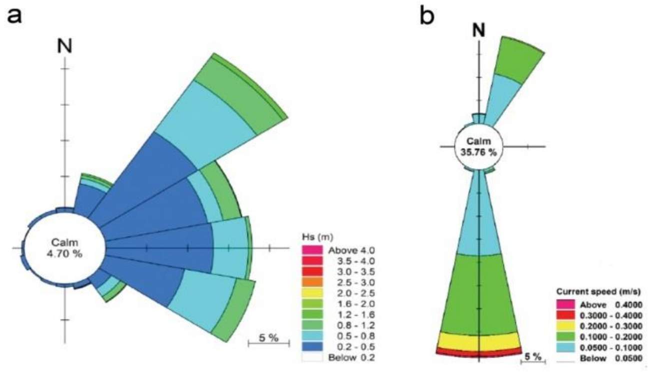


Figure 3. (a) Wave rose and (b) current rose for study site based on observations by Iran's Ports and Maritime Organization

2.1. Scope of present work

One of the objectives of this study was to identify how breakwaters extended in the port of Astara affected the beach topography. Therefore, changes in the bottom topography due to the structures were observed in different years. In addition, this study aimed to modify Dean's equilibrium beach profile model so that it can be a representative model for the study area.

3.Methodology

In this study, morphological evolution in the vicinity of the breakwaters constructed in Astara Port was monitored to investigate the effects of the structures on sediment transport and beach morphological evolution of the study area. After extracting the profiles, monitoring and comparing all the profiles obtained from the collection of topographic data of different years by Plot Composer method from the subsets of Mike Zero module of Mike software, is another step that was done at this stage and the results are graphs obtained from soft processing. Software provided. By analyzing and aggregating them, the sedimentary morphodynamics of the bed profiles in the study area was evaluated. Using Dean (1991) theory and its governing relations, an analytical relationship was presented for the profiles of the study area with the help of Spss and Excel software. Then the profiles extracted from historical and field measured data were compared with the profiles obtained from the analytical relationship ($y= 0.02x^{3/4}$) , and thus, the degree of concordance of the proposed analytical relationship with the bedside profiles in the study area, Checked out. The results are shown in the form of processing graphs.

3.1. Field Works and Data Base

In order to assess changes in the bottom topography due to the extension of breakwaters of Astara Port, two data sets were used: bathymetric profiles, bathymetric surveys. Using a multi-beam echo sounder, cross-shore bathymetric profiles were surveyed by the Iran National Cartographic Center (INCC) in 2009 and 2011, four of which were extracted to represent the cross-shore profiles of the case study area (Figure 4). The data had a vertical accuracy of ± 5 cm and a horizontal accuracy of 1 m.

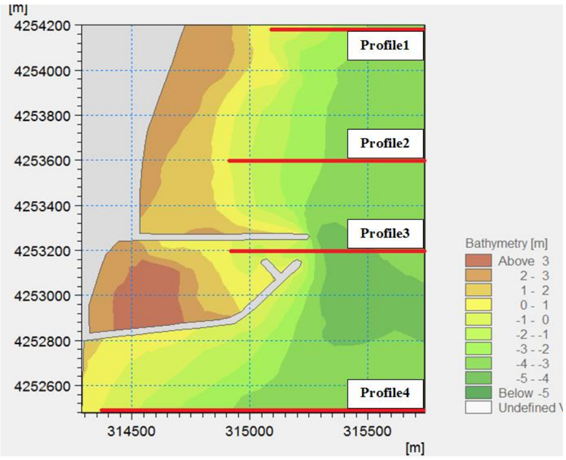


Figure 4. Locations of transects where cross-shore profiles were measured in 2009 and 2011

In 2015, four cross-shore bathymetric profiles were surveyed using a single-beam echo sounder, which had a spatial resolution of 4 m and a vertical resolution of ± 5 cm. The profiles were numbered B, E, G and M. Profile B was sited to the north of Astara Port; profile E was positioned to the upstream side of the port; profile G was located in front of the northern breakwater of Astara Port; profile M was sited to the downstream side of the port (Fig. 5). The profiles are spaced at intervals of approximately 400 m, with an offshore extension of 1400 m.Bathymetric soundings extended to a water depth of 5 m.

Figure 5. Locations of transects where cross-shore profiles were measured in 2015

4.Results

The equilibrium profile described by Dean (1991), $h = Ax^{2/3}$, is mainly based on sediment characteristics, in particular grain size (Karunarathna et al. 2011).(Figure 6) compares cross-shore profiles measured by INCC and Dean’s profile corresponding to A=0.02, which was determined based on the sediment characteristics in the study area. It was noticed that there was a considerable difference between the cross-shore profiles and Dean’s profile. Therefore, the equilibrium profile described by Dean was modified using SPSS statistics (SPSS Inc) and a new profile, representative for the study area, was proposed. This profile is given by the following:

$h=Ax^{3/4}$

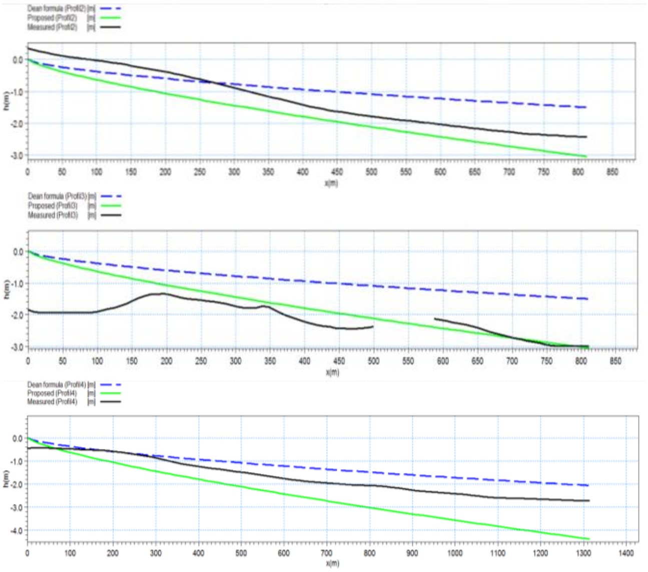
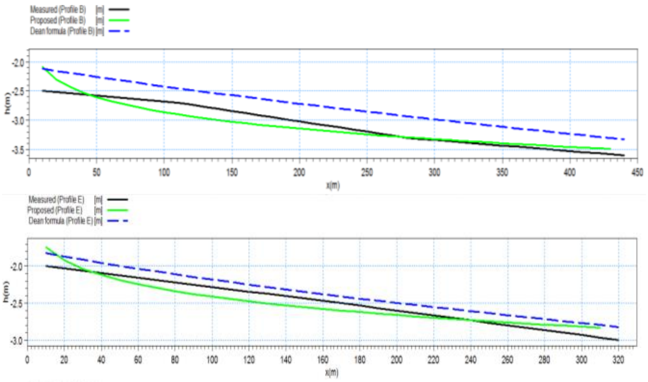


Figure 6. Comparison of cross-shore profiles measured in 2009 and 2011 with Dean’s equilibrium profile and proposed equilibrium profile

As can be seen from (Figure 6), cross-shore profiles were better represented by the modified profile than Dean's one. In addition, (Figure 7) shows that there was also a good agreement between the profiles obtained from proposed model and the cross-shore profiles measured in 2015, in particular profiles located far from the breakwaters. As said before, the presence of breakwaters may affect waves, and wave-induced nearshore currents, causing changes in bottom topography, especially in vicinity of the structures. For example, scouring in front of the breakwaters of the port was noted. By investigating how cross-shore profiles changed at near and far distances from the breakwaters, it was also found that profiles sited far from the breakwaters were less affected by the structures and approximately maintained their natural shape. In addition, since the port obstructed the natural sediment longshore transport, accretion on the north side and erosion on the south side of the port were noticeable.



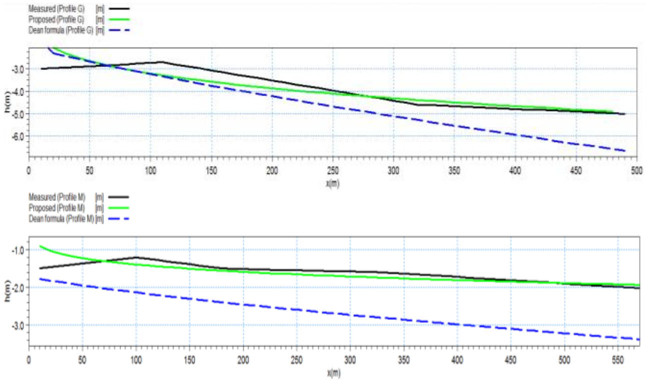


Figure 7. Comparison of cross-shore profiles measured in 2015 with Dean's equilibrium profile and proposed equilibrium profile

5.Conclusion

Coastal protection engineering works may result in changes in characterization of the hydrodynamics and bottom topography of the nearshore domain. Since measuring the changes in underlying bathymetry is very difficult and expensive, developing equilibrium beach profiles which can demonstrate the important features of the bottom topography is of importance. In order to assess the bottom topography of Caspian Sea in vicinity of Astara Port, some field measurements of beach profiles were carried out and some profiles were extracted from hydrographic data observed by Iran National Cartographic Center. The agreement between the profiles and the equilibrium profile described by Dean were investigated, and Dean's profile was modified using SPSS statistics. resulting in a new profile which was shown to be better representative for areas near Astara Port. The proposed equilibrium beach profile was $y=0.02x^{3/4}$. However, there was a good agreement between the cross-shore profiles far from the breakwaters and Dean's profile. This means that Caspian Sea's beach profiles which are not affected by coastal structures behave like those of other coastal waters and open seas. In addition, investigating profiles in vicinity of Astara Port showed that the breakwaters have caused the disturbance to the southward longshore sand transport, leading to beach accretion on the northern side and shoreline erosion in the lee of the structures. Results also showed that waves hitting the breakwaters suspend sediments from the toe of them, and as a results of presence of breakwaters, longshore currents in eastern area of the head of the primary breakwater have enough velocity to move suspended sediments.

In these areas, therefore, more considerable changes were observed in beach profiles. Furthermore, the northern breakwater of Astara Port causes sediments in its lee to deposit, and a lack of sediment within the littoral currents causes severe erosion on the southern coasts of the port.

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