

ANALYSIS OF EMBAYED BEACH PLANFORM STABILITY IN DANANG, VIETNAM

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ABSTRACT

This study presents an analysis of the planform stability of the complex embayed beach system of Da Nang Bay, central Vietnam. As a result of the intensification of extreme weather conditions and human activities in this area (e.g. land reclamation, river damming, and coastal structures), coastal safety as well as economic and ecological values are under pressure. In order to anticipate future changes in the system, it is important to understand the morphological stability of the beaches in Da Nang Bay.

To obtain more insight into the hydrodynamics and morphodynamics of embayed beaches, we first employed the simple parabolic bay shape equation (PBSE) to determine the empirical morphological stability of the beaches: stable, dynamic equilibrium, natural reshaping or unstable. It was found that the predicted planform stability of the beaches in Da Nang Bay does not correspond to the observed behavior.

It is hypothesized that the discrepancies between predicted and observed behavior of the embayed beaches in Da Nang Bay could possibly be attributed to a) the seasonal availability of sediment from the two rivers discharging in Da Nang Bay and b) the seasonality of the dominant wave direction that mainly determines the planform stability resulting from the PBSE. The aim of this study focuses on point b) and is twofold: 1) to obtain more insight into the planform stability of the beaches in Da Nang Bay by applying a more advanced model to predict the wave climate and 2) to investigate seasonal variations in dominant wave direction affect the planform stability.

Keywords: Headland, wave direction, wave climate, diffraction, parabolic bay shape

1. INTRODUCTION

Headland bay beaches can be found in many countries over the world. In general, they occupy about 50% of the world's coastlines with different sizes, shapes and geometry (Hsu et al., 2010; Lausman, et al., 2010). The distinguished curved shoreline planform has attracted researchers to define the equilibrium shoreline planform using different models. These models include the logarithmic spiral (Yasso, 1965), parabolic bay shape (Hsu and Evans, 1989; Silvester and Hsu, 1993, 1997), and hyperbolic tangent (Moreno and Kraus, 1999). Among these models, the parabolic bay shape equation (PBSE) of Hsu and Evans (1989) is now the most popular, accepted and commonly used in coastal engineering practice (Iglesias, et al., 2010; Jackson and Cooper (2010), Gonzalez et al., 2010; Daly et al., (2014). Empirical models, such as the PBSE, basically define the static equilibrium planform of an embayment using a single representative wave direction, down-coast control point (DCP) and wave diffraction point.

In Da Nang Bay (Figure 1), a natural headland with attaching sea port is located north of Da Nang city, with its connection to the East Sea in northeastern direction. It is bounded by Hai Van Mountain to the north, bay beach Nam O to the west and Son Tra Peninsula to the east. There are two seasonal river discharging into Da Nang Bay, the Cu De River from the west and the Song Han River from the south. Due to its geographical location, Da Nang is one of the cities in Vietnam most affected by natural disasters and extreme weather conditions (Dieu, et al., 2012).

During the last decades, several coastal structures were built in Da Nang Bay, such as seawalls, breakwaters, dams and bridges, as well as other human interventions such as land reclamation for the construction of luxurious resorts. These human activities together with the effects of climate change potentially pose a threat to the coastal safety of Da Nang Bay. In order to obtain more insight into hydrodynamic and morphodynamic behaviour of the embayed beach, we initially employ the simple parabolic bay shape equation (PBSE). The PBSE can be used to determine the empirical morphological stability of the bay, which can either be stable, in dynamic equilibrium, natural reshaping or unstable.



Figure 1. Location of Da Nang bay (google earth image)

Many studies currently applying the PBSE to cover complex bay shapes have pointed out problems regarding the uncertainties due to the choice of the control points and limitations of its application range (e.g., Martino, Moreno, and Kraus, 2005; Gonzalez and Medina, 2001; Jackson and Cooper, 2010; Lausman et al., 2010). For complex bay beaches, the equilibrium plan shape cannot be determined from a single wave direction such as the empirical parabolic bay shape model (Daly et al., 2011, 2014). In the study of Daly et al., (2014), they found that a variable wave climate can have an influence on the equilibrium orientation and shoreline planform of the bay. Two other factors that have a potential effect on the equilibrium planform are the role of local bathymetry and the presence of the other morphological structures capable of causing significant wave refraction/diffraction influencing stability. These factors are ignored when using the empirical PBSE. Illustrating these effects, Jackson and Cooper (2010) found the ebb tide delta as a diffraction point rather than the adjacent rocky headland. Moreover, Ferraz (2014) demonstrated that the local morphology (delta) created significant wave refraction and they used the position of the delta structure as the updrift control point instead of using the prominent headland as diffraction point in the PBSE model.

In order to gain more understanding about the possible discrepancies between observed and predicted behavior using the PBSE of the embayed beach, we initially focus on the effect of seasonality in wave climate impact on the bay beach planform in Da Nang Bay. Delft3D WAVE was used in combination with the PBSE to investigate if wave propagation over the local bathymetry including the complex headland can influence the location of the control points. Consequently, we investigate if the results motivate an extension of the PBSE.

2. METHODOLOGY AND RESULTS

First, we apply the PBSE without prior knowledge of the wave conditions. It should be noted that a static equilibrium of the bay shape is assumed when applying the PBSE. In a second step, Delft3D WAVE is used to translate offshore wave conditions towards local wave conditions within the complex environment of Da Nang bay.

2.1 Empirical parabolic bay shape approach applied to Da Nang bay

Hsu and Evans (1989) developed a second-order polynomial equation based on fitting 27 mixed cases of 14 prototype and 13 model bays believed to be in static equilibrium. Their equation for the parabolic shape of a headland-bay beach in static equilibrium has the general form of

$$\frac{R}{R_0} = C_0 + C_1 \left(\frac{\beta}{\theta} \right) + C_2 \left(\frac{\beta}{\theta} \right)^2 \quad [1]$$

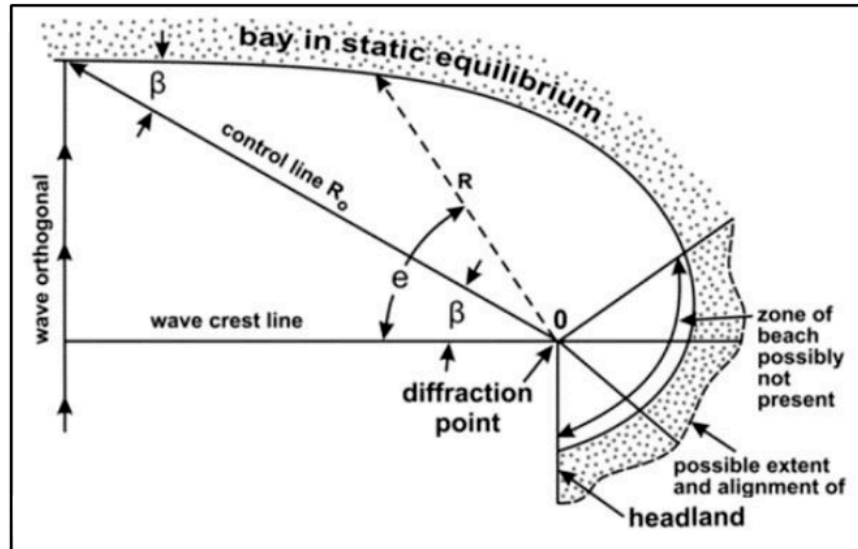


Figure 2. Definition sketch for the parabolic bay shape model (Hsu and Evans (1989), adapted by Lausman et al. (2010)

In the definition sketch (Figure 2) and Eq. [1] there are two basic parameters, β and R_0 . β is the reference wave obliquity angle, which is the angle between the incident wave crest (assumed linear) at the wave diffraction point and the control line (R_0), joining the updrift diffraction point to the near straight downdrift beach. The radius R to any point on the bay periphery in static equilibrium, is at an angle θ from the same wave crest line radiating out from the wave diffraction point. The three C constants differ with reference angle β (Hsu and Evans, 1989). These C values are bounded between -1.0 and 2.5 for the usual range of β from 10° to 80° applicable in most field conditions (Silvester and Hsu, 1993).

In order to properly apply the parabolic bay shape equation for a complex bay beach system, there is a need to carefully choose the upcoast and downcoast control points as well as the representative wave direction. Selecting the control points is especially difficult for a bay beach of unknown stability such as Da Nang bay. Hence, in this study, it is initially assumed that the bay beach is in static equilibrium and the tangent, at an appropriate point on the straight downdrift section, is assumed perpendicular in direction to the local incident wave propagation at the updrift diffraction point (Hsu et al., 2008). Based on this assumption two tangent lines were identified along with the dominant wave direction. MEPBAY software (Klein et al., 2003) derived from the PBSE is used to predict idealized shoreline in static equilibrium at Nam Chon cape (see Figure 1). based on these two dominant wave directions The results of the empirical parabolic bay shape model are shown in Figure 3.

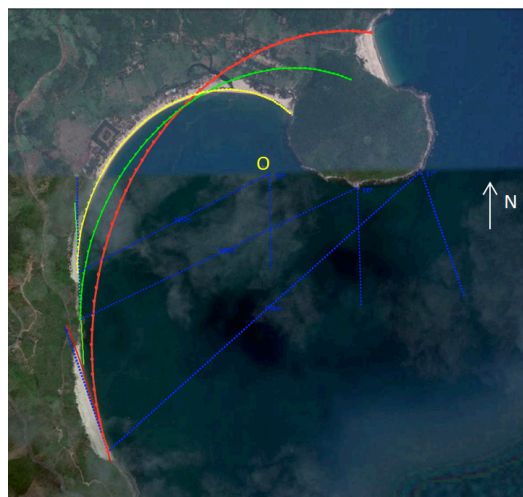


Figure 3. Parabolic bay shape approach for Nam Chon cape for different dominant wave angle approaches (red_line (75°); green_line and yellow_line(89°)

It is interesting to note that the actual shoreline of Nam Chon beach fits the parabolic curve rather well when the control point (O) is not located at the tip of the headland. Despite the shoreline is well represented by the parabolic curve, the meaning of point O is unclear. Point O can be interpreted as point of diffraction but it is not located at the tip of a headland. Therefore, we cannot confirm the validity of the result of the PBSE for this bay. We hypothesise that seasonality in the wave climate might influence the location of the point of diffraction. To address the seasonal signal in the wave climate we have analysed the wave climate offshore (using NOAA WAVEWATCH III archives) in combination with Delft3D modelling software. The results are illustrated in Section 2.2 and 2.3

2.2 Wave climate

Information about the wave climate in the study area is very poor. There are three visual observations of wave height and direction per day. However, the location of the observation is at the Son Tra Mountain and consequently the results do not reflect the wave characteristics of the Da Nang coast. Hence, this study uses the waves extracted from NOAA WAVEWATCH III hindcast reanalysis (<http://polar.ncep.noaa.gov/waves/>) at the grid point (16.5°N, 108.5°E) to define the wave climate at Da Nang coast. The data is based on the global wave (0.5°x 0.5°) from 1/02/2005 to 31/01/2014 at 3-hour intervals, at 00:00h, 03:00h, 06:00h, 09:00h, 12:00h, 15:00h, 18:00h and 21:00h every day.

Wave direction is one of the principal variables when characterizing the forcing factors that act on the coast in terms of morphodynamics. The following rose diagrams illustrate the wave heights, wave periods and the directional distributions for the entire data set, in which the wave climate can be categorized into two seasons, e.g. winter season and summer season.

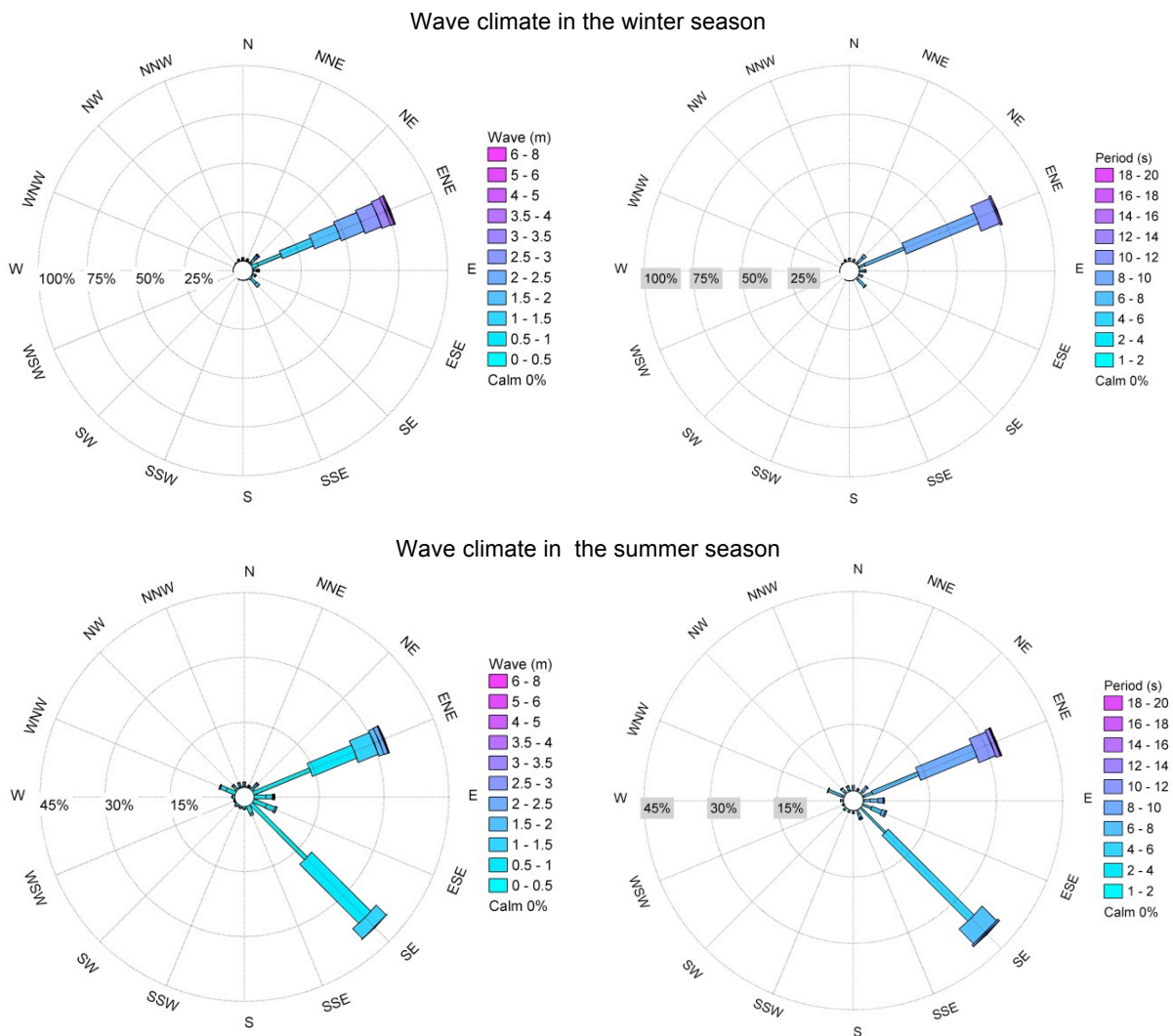


Figure 4. Seasonal wave direction in relation with wave height H_{sig} (left) and wave period T_m (right)

From Figure 4 it is clear that there was variation in wave height, wave period and the directional distribution of the waves. Due to the NE monsoon regimes, waves in the winter season (from September to March) were dominated by the ENE (76.74%) with wave heights ranging between 0.5 and 3.0 m and periods between 8 and 10 s. In the summer months (April to August), the waves were characterized by a bi-directional configuration. The waves were clearly influenced by the SE component and ENE directional component. The first dominant direction was from SE (40.45%) with wave heights of 0-1.0 m and periods of 4-6 s (27.40%). The second dominant wave direction was ENE (32.78%) with typical wave heights of 0.5-1.0 m and periods of 6-10 s. The highest wave heights normally occurred during winter months due to typhoons or tropical storms and may reach up to 4-7 m in direction of N, NE, ENE, E and ESE. In general, the waves during the winter season had higher energy and longer periods than the waves in summer season.

2.3 Wave modelling

The WAVE module of Delft3D was used to simulate wave propagation (refraction and diffraction) and dissipation (depth-induced breaking) inside Da Nang Bay. The wave boundary conditions were modeled according to the main wave directions (ENE and SE) using the most frequent values of significant wave height and period in the derived data sets of the wave climate. The local bathymetry inside of Da Nang Bay was obtained through the University of Da Nang and the bathymetry outside of Da Nang bay was obtained from the Gebco08 bathymetry data set (http://www.gebco.net/data_and_products/gridded_bathymetry_data/), which has a grid resolution of 30 arc-second spacing. The wave conditions were used to relate the wave behaviour to local bathymetry in order to characterize the overall wave propagation and specifically the near shore wave direction around the diffraction point. The results of the wave modelling in ENE and SE direction are shown in Figure 5. To increase the detail inside the bay, the Nam Chon region (red rectangular region) was modelled at a higher grid solution nested within the regional model. Model results show that refraction and diffraction occur both for ENE and SE wave direction resulting in a similar wave direction at the Nam Chon region. The simulated wave direction at the tip of the Nam Chon headland are for offshore waves from ENE and SE, 85.45° and 83.7° respectively. The similar wave directions at the tip of the Nam Chon headland due to waves propagating from ENE and SE direction from offshore into the bay indicate that the dominant wave direction inside of the Da Nang bay is only slightly dependent on the seasonal wave climate measured offshore. In the case of Da Nang bay, the headland has an important role in wave diffraction, however, in order to assess stability of the planform we need to further account for more factors that affect the stability such as wave heights, wave periods and headland geometry.

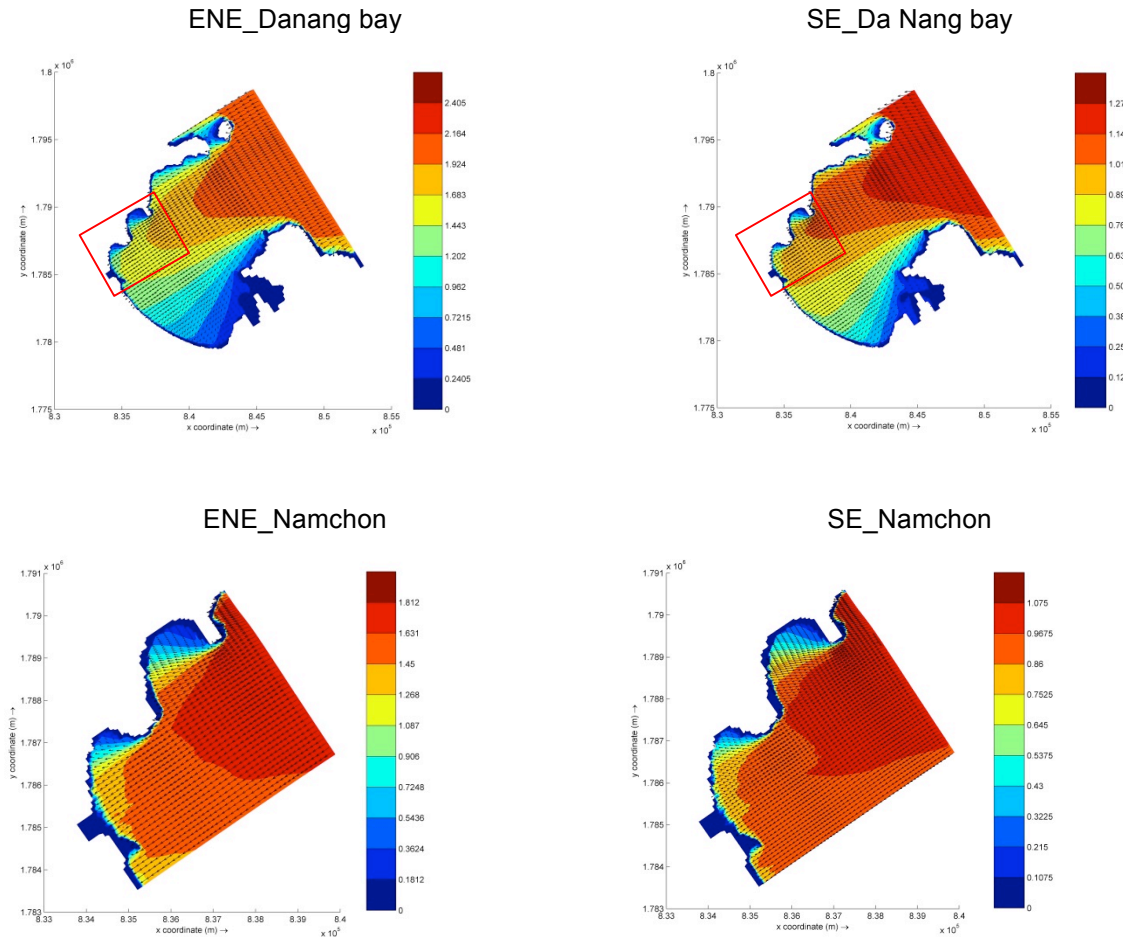


Figure 5. Model results for ENE direction (67.5°) on the left and SE direction (135°) on the right and color bar represent the wave heights.

3. CONCLUSIONS

We have applied the PBSE to explain the shape of a particular bay located in Da Nang, Vietnam. The complexity of this bay leads to uncertainties with respect to the selection of both downdrift and updrift control points associated with the PBSE. Especially the occurring bi-modal wave conditions in the East Sea might lead to a difficult interpretation of the PBSE. We have used the shallow water wave propagation model Delft3D WAVE to predict local wave conditions inside the bay and we have found that seasonality within the wave signal in the East Sea does not affect the local wave direction inside Da Nang Bay. We are therefore encouraged to use the PBSE equation to predict the development of the bay. However, uncertainty regarding the updrift control points continues to exist due to the complex shape of the updrift

headland. Additional process based modelling might provide more information on the validity of the assumptions behind the PBSE.

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