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Dynamic equilibrium planform of embayed beaches: Part 1. A new model and its verification

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ABSTRACT

Equilibrium beach formulations are useful tools for diagnosing and managing coastal engineering problems, providing solutions for beach erosion problems. Headland Bay Beaches (HBBs) can be used as equilibrium coastal systems for stabilizing coastlines and mitigating erosion problems. These embayed beaches may exist in a state of static or dynamic equilibrium. Throughout the literature, several equations can be found for obtaining the Static Equilibrium Planform (SEP) of Headland Bay Beaches (HBBs) with almost negligible net littoral drift rates. However, the formulations used to define the Dynamic Equilibrium Planform (DEP) of embayed beaches with specific net sediment transport rates are scarce, and based on a limited number of studies. This paper proposes a new derived formula for obtaining the planform shape of HBBs in dynamic equilibrium conditions. The formula represents a general form of the Parabolic Bay Shape Equation (PBSE) with modified coefficients as a function of both the wave obliquity (β) and the net littoral drift rate passing through the bay (Q). The angular difference (γ_d) between the direction of the mean wave energy flux at the diffraction point of the headland and the beach orientation down-coast is also incorporated in the proposed formula. The model was verified against natural HBBs in dynamic equilibrium with different net littoral drift rates along the Brazilian coast, producing good results.

1. Introduction

Embayed beaches are a common physiographic feature all around the world. It is estimated that they occupy about half of the world's coastlines (Inman and Nordstrom, 1971). They have been termed by a variety of names as reported by Hsu et al. (2010). These names include crenulate-shaped bays (Silvester and Ho, 1972; Hsu and Evans, 1989; Weesakul et al., 2010), spiral beaches (Krumbein, 1944; LeBlond, 1972), pocket beaches (Komar, 1983; Silvester et al., 1980; Uda et al., 2002), headland bay beaches (Yasso, 1965; LeBlond, 1979; Wong, 1981; Phillips, 1985; Moreno and Kraus, 1999; Klein and Menezes, 2001) and headland embayed beaches (Short and Masselink, 1999). Headland Bay Beaches (HBBs) on oceanic and coastal margins exist at the downdrift of protruding headlands and man-made breakwaters. They appear in different sizes and various configurations (Hsu et al., 2008). The planform of HBBs may be in a static equilibrium, dynamic equilibrium, unstable or natural reshaping state. A static equilibrium HBB is a state where the predominant waves are breaking simultaneously around the whole bay periphery; hence the net littoral drift produced by longshore currents is almost non-existent and no additional sediment is required to maintain its long-term stability (Hsu et al., 2010; González et al., 2010). In such conditions, the shoreline has its maximum indentation in the planform. On the other hand, a HBB is considered to be in a state of dynamic equilibrium when sediment, from updrift and/or a source within the embayment, is passing through the bay's periphery in which the incoming and outgoing sediment transport rates are equal (Hsu et al., 2008, 2010; Klein et al., 2010). In this dynamic condition, the shoreline is not as indented as that of the static equilibrium condition. If the sediment supply ceases, the shoreline will then recede towards the position defined by the static equilibrium.

Several empirical equations can be found throughout the literature to obtain and fit the Static Equilibrium Planform (SEP) of embayed beaches, e.g. the well-known Parabolic Bay Shape Equation (PBSE) proposed by Hsu and Evans (1989) and its subsequent modifications, (e.g. by Tan and Chiew, 1994; Mita, 2010; Uda et al., 2010). However, equations used to obtain and best fit the Dynamic Equilibrium Planform (DEP) of an

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embayed beach with a specific net rate of littoral drift (Q) are rare in the literature and based on only a limited number of case studies, see Tan and Chiew (1993) and Tasaduak and Weesakul (2016). Furthermore, their application to practical engineering problems is limited and they cannot be used for the design of non-existing beaches in zones with dynamic equilibrium conditions.

Accordingly, the aim of this paper is to propose a new general formula that defines the shape of the equilibrium planform of embayed beaches in dynamic equilibrium conditions. The study hypothesizes that the (DEP) can be represented and defined using a second-order polynomial form like the PBSE, while taking into account the net littoral drift rate (Q) passing through the embayment. Furthermore, this new equation can be used for the design of non-existing HBBs in zones with known sediment transport rates.

The paper is organized as follows: First, a general introduction to embayed beaches and their equilibrium states is presented. This is followed by a brief review of some of the previous investigations of dynamic equilibrium bayed beaches, which is detailed in section (2). The derivation of the new formula is given in section (3), and its verification against HBB cases from the field is presented in section (4). A discussion of the verification results of the new model is delineated in section (5), and, finally, the conclusions of this study are given in section (6).

2. Previous investigations

Hsu and Evans (1989) derived the PBSE, which is a second-order polynomial equation derived from fitting the planform of 27 mixed cases of prototype and model bays believed to be in static equilibrium as explained in Fig. 1 and is given as:

$$\frac{R}{R_o} = C_0 + C_1\left(\frac{\beta}{\theta}\right) + C_2\left(\frac{\beta}{\theta}\right)^2 \tag{1}$$

Where (R_o) is the length of the control line joining the updrift diffraction point to the down-coast control point (P_o) and inclined (β) to the wave front at the diffraction point. The three C coefficients are functions of the wave obliquity (β), i.e. the angle between the incident wave front and the control line. The radius (R), measured from the tip of the headland breakwater, defines the locations of the shoreline at an angle (θ), measured from the wave crest.

Tan and Chiew (1993, 1994) noted that the original PBSE of Hsu and Evans (1989) did not account for the tangential boundary condition at the down-coast control point (P_o) when (R=R_o & β=θ), and they therefore considered the following boundary conditions at that point:

$$C_0 + C_1 + C_2 = 1 \tag{2}$$

$$C_1 + 2C_2 = \beta cot\beta \tag{3}$$

Consequently, they derived a new version of Eq. (1), proposing the following form:

$$\frac{R}{R_o} = (1 - \beta cot\beta + \alpha) + (\beta cot\beta - 2\alpha)\left(\frac{\beta}{\theta}\right) + \alpha\left(\frac{\beta}{\theta}\right)^2 \tag{4}$$

As a result, they reduced the number of unknown coefficients from three to one, (α), which represents the C_2 coefficient in Eq. (4). They derived the (α) parameter as a function of the wave obliquity (β), based on measured shapes of the model beaches, and proposed the following expressions for both static and dynamic equilibrium conditions:

$$\alpha_{st} = 0.277 - 0.0785 \times 10^{\left(\frac{\beta\pi}{180}\right)} \tag{5}$$

for static equilibrium

$$\alpha_{dy} = -0.004 - 0.113 \times 10^{\left(\frac{\beta\pi}{180}\right)} \tag{6}$$

for dynamic equilibrium

Where the (α) parameter has the values of (α_{st}) and (α_{dy}) for static and dynamic equilibrium conditions, respectively. They stated that the

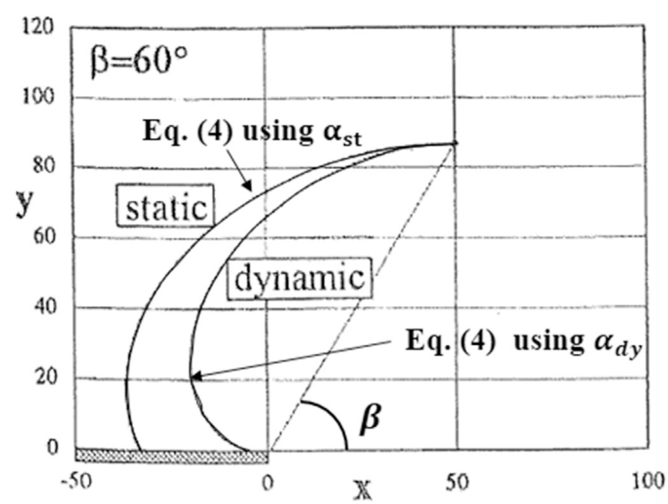

Fig. 2. Static Equilibrium Planform (SEP) shape of Tan and Chiew (1994) applying Eq. (4) using the (α_{st}) parameter in addition to the dynamic planform shape for the case of maximum littoral transport rate as defined by Tan and Chiew (1993) applying Eq. (4) using the (α_{dy}) parameter, modified from Tan and Chiew (1993).

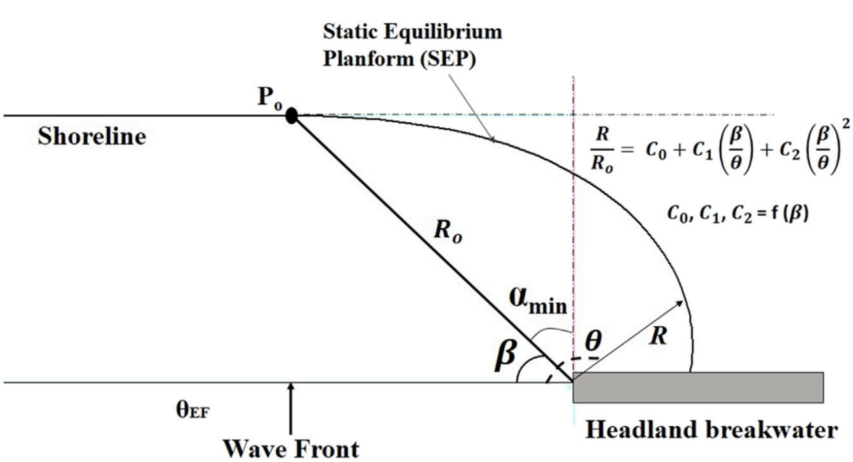

Fig. 1. . Definition sketch of the Parabolic Bay Shape Equation (PBSE) for an embayed beach in static equilibrium proposed by Hsu and Evans (1989).