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Typical Equilibrium Beach Profile Models and Their Significances from Different Segments of A Headland-Bay Beach*

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ABSTRACT

This study introduces three typical models on equilibrium beach profile, and discusses the application limitations of these models. Then this study examines the selections for applying these models on different coastal segments of a headland-bay beach in west Guangdong, South China, and explores the physical significances of those parameters in the models. The results indicate that: (1) Bodge's model is more in line with the equilibrium beach profile of the tangential or transitional segment, whereas Lee's model is more consistent with the shadow profile; (2) most of the parameters in three models have clear physical significances in accordance with the actual characteristics of this headland-bay beach; and (3) both the selections for the equilibrium beach profile from different segments and significances of most of the parameters in three models are in essence correlated with the morphodynamic states at various coastal locations.

Key words: *equilibrium beach profile*; *Bruun/Dean's model*; *Bodge's model*; *Lee's model*; *parameter significances*; *headland-bay beach*

1. Introduction

A beach profile refers to the morphology of the beach perpendicular to the high-tide shoreline; it may extend out through the breaker zone and into deep water offshore, and the landward limit tends to end at the berm or backshore (Komar, 1997). An equilibrium beach profile represents the profile morphology which has adjusted its shape to the long-term wave climate (Bruun, 1954; Komar, 1997). The concept of the equilibrium beach profile, historically proposed by Fenneman (1902), is based on the assumption that a beach, characterized by a specified grain size, assumes an equilibrium profile under constant wave forcing. Even though the sediment could be in motion, net cross-shore sediment transport does not exist along the profile. The general characteristics of the beach profile is that it has steep slope at the shore which decreases progressively as the water depth increases offshore (Komar, 1997). A great number of equilibrium beach profile models have been proposed through more than fifty years of

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development. Aside from three representative models by Bruun (1954), Dean (1977), Bodge (1992) and Lee (1994), many other efforts have been devoted to defining the shape of the equilibrium profile with different formulations under different conditions and influencing factors (Kit and Pelinovsky, 1998; González and Median, 1999; Larson *et al*., 1999; Romanczyk *et al*., 2005; Dai *et al*., 2007; Hsu *et al*., 2006; Özkan-Haller and Brundidge, 2007; Walton and Dean, 2007; Dong, 2008; Turker and Kabdasli, 2009; Kaiser and Frihy, 2009). Work concentrates on those empirical equation validations of equilibrium beach profile and their parameter estimations, but also considers the selections of those empirical equations according to different types of beaches. Research achievements have been applied to many coastal engineering projects. As the equilibrium equation is the principle assumption of the most of the numerical modelling, the equilibrium profile theory has been incorporated in many models used in coastal engineering, mainly developed by the U.S. Army Corps of Engineers: the ACES suite of software (Leenknecht *et al*., 1995), the CMS package (Cialone, 1994), and the GENESIS model (Hanson and Kraus, 1989). The concept of equilibrium beach profile is also applied in the SBEACH model (Larson and Kraus, 1989), and used to examine shoreline change due to the cross-shore sediment transport. Additionally, the concept of equilibrium beach profile has been widely used for predicting beach nourishment projects (Elko and Wang, 2007; Risio *et al*., 2010; González *et al*., 2010). In particular, Dean's (1991) method, based on the concept of equilibrium beach profile, is frequently used in beach fill design to estimate the sediment volume needed to achieve a desired dry beach width (Houston, 1996).

However, little concern focuses on this in China (Chen, 1996, 1997; Yin *et al.*, 2001; Li and Chen, 2002, 2008, 2009). Perhaps Chen (1996) firstly noticed equilibrium beach profiles in China. By two measured profile data in the Jinghai Bay in East Guangdong province, he utilized Bruun/Dean's model, Bodge's model and Lee's model to this bay, and found that the nearshore profile shape of the Jinghai Bay was more in line with Bodge's model and Lee's model. In addition, Chen (1997), and Li and Chen (2002) reviewed the development of equilibrium beach profile, respectively. Along a straight coast of Rizhao City in Shandong province, Yin *et al*. (2001) studied the application of Bruun/ Dean's model, and observed that as the beach sediment granularity has obvious characteristic zonation, and the beach profile of this coast consisted of two segment equilibrium beach profiles compatible with the sediment granularity. More recently, Li and Chen (2008, 2009) have made use of Bruun/Dean's model, Bodge's model and Lee's model to Houjiang Bay in East Guangdong province and discussed some parameters' physical meanings and correlation among those models. Beach profile data were obtained by eight beach profiles, which were nearly equal spacing layout from the Houjiang Bay chart contours.

Headland-bay beaches spread widely and exceed 100 locations along the south coast, from East Guangdong province to Hainan Island, except those bays adjacent to large estuaries in South China (Li and Chen, 2006; Yu and Chen, 2011). Comprehensive studies on equilibrium beach profiles of these headland-bay beaches in South China will provide more theoretical basis and technical support for Chinese coastal engineering, management, beach nourishment and erosion prevention. Thus, the objectives of this paper are: (1) to introduce three kinds of typical equilibrium beach profile models –Bruun/Dean's model, Bodge's model and Lee's model, and to discuss the application limitations of these three models; (2) to examine the applications of these three typical models on different coastal segments of a wave-dominated, meso-tidal headland-bay coast through the tangential, transitional, and shadow profile data in the Shuidong Bay in West Guangdong of South China; and (3) to explore these parameters' significances and relationships in the three models.

2. Three Equilibrium Beach Profile Models and Their Discussions

2.1 Three Representative Equilibrium Beach Profile Models

2.1.1 *Bruun/Dean's Model*

Bruun (1954) analyzed beach profiles from the Danish North Sea Coast and Mission Bay, California, and found that they followed a simple 2-parameter power function of the form:

$$h(x) = A_1 x^m, \tag{1}$$

where, h is the still water depth, x is the horizontal distance from the shoreline, and A_1 and m are empirical coefficients from the fitted profile (Komar and McDougal, 1994).

Based on 504 beach profiles collected by Hayden *et al.* (1975) along the U. S. Atlantic Ocean and the Gulf of Mexico coasts, Dean (1977) used a least squares fitting procedure to analyze these profiles, and found that the value of m was in the range from 0.2 to 1.2 characterized as a normal distribution, and its mathematical expectation was 2/3. It was suggested that the most appropriate form of equilibrium beach profile is given in the following equation:

$$h(x) = A_1 x^{2/3}. \tag{2}$$

In case the parameter m is fixed at 2/3, and the equation is simplified to the only free variable function.

2.1.2 *Bodge's Model*

Following the first efforts of Bruun (1954) and Dean (1977), an exponential beach profile was illustrated by Bodge (1992) based on beach-face slope and the closure depth,

$$h = B(1 - \mathrm{e}^{-k_1 x}), \tag{3}$$

where, h is the still water depth, x is the horizontal distance from the shoreline, and B and k_1 are empirical coefficients. Eq. (3) is a 2-parameter exponential function form. The fitted results from Eq. (3) are closer to the measured profiles from the Hayden *et al.* (1975) dataset than those from Eq. (2). The results noted more consistency with measured profiles than those suggested by Dean (1991).

2.1.3 *Lee's Model*

Lee (1994) expressed the geometry of the equilibrium profile in an explicit form in relation with the offshore wave period (or wave length) using the Airy Wave Theory.

$$x = A_2(\mathrm{e}^{k_2 h} - 1), \tag{4}$$

where, x is the horizontal distance from the shoreline; h is the still water depth; A_2 is a constant, named extension factor, which may be related to grain size; k_2 is a parameter assigned as $2\pi/L$, where L is the offshore wave length, or a function of a corresponding offshore wave period T.

2.2 Discussion of Three Models and Their Parameter Significances

2.2.1 *Hypothesis of Three Models*

Bruun (1954) defined the water depth as a function of the offshore distance, assuming that equal bottom stresses are exerted by waves on beach profiles. Dean (1977) theoretically supported Bruun's theory assuming that the equilibrium conditions at coastal profiles can be achieved when wave energy dissipation per unit water volume along the profile becomes constant. However, Lee (1994) discussed Dean's profile implying that Dean's hypothesis relating the wave energy dissipation with the particle movement is a vague one since energy is a scalar quantity but not a vector. A random disturbance of sand and water may dissipate a great amount of energy without any necessary bottom geometry change. Similarly, any symmetrical cyclic movement within a fluid may be attenuated by dissipating its energy into heat without changing the shape of bottom geometry into another definite shape. Therefore, a dynamic model of the equilibrium profile by Lee (1994) may be more reasonable than an energetic model by Bruun (1954) or Dean (1977) because the former is based on the balance of forces which are vectors related to the shape of the profile with definite mechanisms.

2.2.2 *Physical Significances of the Parameters in Three Models*

The parameter, m, in Bruun/Dean's model is the shape parameter reflecting the reflectivity of the beach profiles. However the physical interpretation of A_1 may be unclear (Komar and McDougal, 1994), as the various parameters are associated with the sediment data and wave conditions of individual profiles. Actually, natural processes controlling beach profile change are not constant. Large differences are often found (Pilkey *et al.*, 1993; Mangorr, 2001) between the observed beach profiles at the shoreface and those predicted by the equilibrium expression of Bruun (1954) and Dean (1977). This has been explained by Moore (1982) and Dean (1987) who assumed that it arose from the sensitivity of the parameter (A_1), where $A_1=0.41(d_{50})^{0.94}$, to changes in the grain size. Thus, a minor error in estimating d_{50} may produce a significant difference in profile shape. Then to some extent, the parameter, A_1, in Bruun's model can depict the sediment sizes.

The physical meaning of k_1 in Eq. (3) can be expressed as the concavity of the profile. According to the analysis by Bodge (1992), the parameter, B, in Bodge's model was the asymptotical depth of the beach profiles which can mirror the closure depth to determine the sediment movement.

The parameter, k_2, in Lee's model is correlated with the offshore wave length, denoted as $k_2=2\pi/L$. Additionally, the relationship between the periods and the wave lengths in deep water can be expressed by $L=gT^2/(2\pi)$. Thus, k_2 can be used to calculate both the wave periods and wavelengths in local coastal area. However, the physical interpretation of A_2 in Lee's model is vague, and may be related to the grain or other physical parameters.

2.2.3 T*he Applications and Some Limitations of Three Models*

Because of the simplicity of Eq. (2), the best known and most commonly used model in applications is still the Dean's profile model and its generalizations, which are used widely to compute the net cross -shore sediment transport and to estimate the stability of beach profiles resulting in a variety of application (McDougal and Hudspeth, 1983a, 1983b; Dean, 1991; Bodge, 1992; Kit and Pelinovsky, 1998). However, there are several shortcomings in Dean's model which limit its broad application. One problem is its dimensionality. Because the unit for term A_1 in Eq. (2) depends on the value of the exponent m, which is equal to 2/3 and the unit for A_1 is $m^{1/3}$. Furthermore, the derivative of the relationship with m=2/3 yields the beach slope variation $S=\tan\beta=\frac{\mathrm{d}h}{\mathrm{d}x}=\frac{2}{3}\frac{A}{x^{1/3}}$, which becomes infinite when x=0 at the shore. In comparison, Eq. (3) can solve this problem. Theorically, based on the balance of forces, Eq. (4) is a dynamic model and has a clear physical interpretation because this equilibrium beach profile equation not only is exhibited in an explicit expression, but also considers the impact of wave periods. However, the natural meaning of the other parameter, A_2, in Lee's model is more obscure than the parameter, A_1, in Dean's model, which ultimately limits the practical application of Lee's model.

3. Background of the Study Area and Data

3.1 Description of the Study Area

Shuidong Bay is located in the west coast of Guangdong province approximately south of Dianbai County, Maoming City. The coast is comprised of a bar, a lagoon, and a tidal channel. About 9 km long barred feature spreading from the northeast to southwest separates the north lagoon from the south sea, leaving a 1 km wide tidal channel which links the lagoon with the open sea. The flood or ebb delta is well developed. The wave energy dissipation effect of the huge ebb delta with small water depth and the resistance of the ebb current with jet flow to the incident wave make the ebb delta to a depositional headland. By the "depositional headland" shielding and the control of Yanjing headland downcoast, there exist characteristic headland-bay sandy coastlines in the west of the bay mouth. The bay is asymmetric in shape, characterized by a curved shadow segment, a gently curved transitional segment, and a relatively straight tangential end downcoast.

The pattern of the tide belongs to irregular semidiurnal tide with the average spring tidal range at 2.6 m. The type of incident waves is mainly wind waves (or sea) with the average wave height of 0.66 m and the average wave period of 4 s. And an SSE wave approach prevails over the course of one year. During the summer months, the prevailing waves from the directions of SE and SEE dominate the bay. According to the conditions of tides and waves, this bay can be classified as the lower wave-dominated, meso-tidal coast (Chen and Li, 1993). The tides, and waves superimposed on the periodic tidal levels, are the essential forces for this beach evolution.

3.2 Profile Data

Three profiles designated No. 1, No. 2 and No. 3 were arranged along the Shuidong Bay, representing the tangential, transitional, and shadow segment, respectively (Fig. 1). Three profile datasets of this study were selected in November 2007. Each profile datum was made up of the water depth and the distance offshore. The water depth calibration was based on the local sea level. The maximal water depth offshore of each beach profile was more than 6 m deep and its offshore distance was approximately from 1400 to 2700 m. As the equilibrium profile shape is mainly used in the simulation of the large-scale and long-term beach morphology simulation, a data filtering method was required to process the original measurement data. In this study, the moving average procedure was used to remove the high frequency information of these profile data.

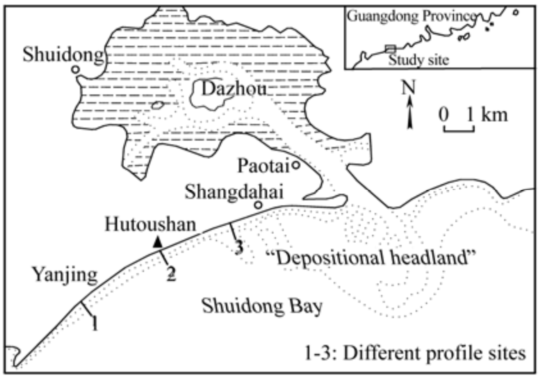

Fig. 1. Position of the study area.

It must be noted that previous studies concentrate on either different beach profiles at various locations or many profiles in a straight coast. Obviously, the former makes the results difficult to compare with each other because of varying coastal conditions and different positions, and the latter may not receive some obviously regular recognition due to less spatial changes of profile properties. In the case that in a headland-bay coast, the coastal environment background is similar and wave energies and associated beach profile characteristics are variable, and then choosing beach profiles at different coastal segments to study the equilibrium beach profile would be more representative and particularly important (Li and Chen, 2009), which is also the motivation of this study.

3.2.1 *Morphodynamic Characteristics of Beach Profiles*

The profile of the tangential segment of this bay begins at the foredune which is composed of a mixture of medium and fine sand. The foredune with the maximal height of about 6 m decreases gradually from the west to the east. This beach consists of a relatively steep, swash dominated beach face, which is linear with the average slope in excess of 7°. But the slope under the beach face significantly becomes gentle with the average slope of 0.03°. The sediment of this profile is mainly coarse sand, and low wave energy and long wave periods dominate this segment. And the reflective beach accompanied by the low tide terrace has been characterized by the persistent berm almost all the year round and ridge-trench feature migrating shoreward in a quasi-periodic way (Chen and Li, 1993; Yu, 2011).

The shadow segment extends eastward to the west side of the tidal inlet, and the sediment of the beach is made up of fine sand or very fine sand. The beach is characterized by a wide, low gradient swash zone, a wide surf zone, driven by spilling breakers which dissipate their energy across the wide surf zone, probably with the existing subaqueous bars and troughs or flatter and more featureless topography without bars (Yu, 2011). The beach, the gentle ridge plain, and connecting low sea-cut scarp are the main topographic features. Sometimes, some small transverse or oblique sandbars can be observed under the low water line. The profile is concave with the average slope of 1.5°.

The transitional segment is located between the tangential and the shadow segments, whose backshore links with the discontinuous gentle foredune. The sediment composition, topographic characteristics and profile morphology vary largely. The subaerial accumulated topography including berm and cusp gradually disappears. Along the longshore direction, the slope of this segment changes from steep to gentle, simultaneously with obvious transformation between the subaerial and subaqueous topography. The beach state belongs to the low tide/rip beach of intermediate state beach types, produced by moderate to high waves, fine sand, and longer wave periods (Yu, 2011). When the subaqueous bar moves shoreward in a quasi-periodic way, berm will be rebuilt on the beach, and the low tide terrace will be formed around low tide level.

3.2.2 *Analysis of Sediments and Equilibrium State*

There is no river transporting sediment to this bay (Li *et al*., 1990), leaving it a relatively independent system. Li *et al*. (1988) presented that the coastline of this study area trended to be back during the modern period, probably dating back the time of only a few hundred years. The reason for retrograding shoreline may be closely correlated with sediment supply. With the long-term stability of the sea level, the sediment from the continental shelf gradually weakened or even terminated, shaping the relative stable subaqueous slope of the Shuidong Bay. Wave refraction and diffraction occurred at the depositional headland resulting from the prevailing wave from the direction of SSE, which moved sediment from the east to the west forming a reverse spit on the west side of the depositional headland. Yu (2011) simulated the average wave field of the Shuidong Bay using modified mild-slope equation and found that longshore sediment transport had almost no impact on the profile of No. 3. Thus, the total sediment budget is nearly in a relatively stable state, and the profile is also in a dynamic equilibrium state. Onshore–offshore sediment transport continuously occurs under the conditions of seasonal wave climate or storm waves. During the fall and winter months, fair-weather wave processes return the material to the surf zone and beach, creating a constructional profile. The data of this study were collected in the winter month of 2007 when the bottom sediment movement was weak, which largely reduced the influence of onshore–offshore sediment transport on the profile morphology.

4. Application of Equilibrium Beach Profile Concept in Shuidong Bay

4.1 Results

The aforementioned profile data were fitted by Bruun/Dean's Model, Bodge's Model and Lee's Model, respectively. The comparative analyses between the fitted results and the measured profile morphology were implemented and the correlation coefficient, R, the residual sum of squares, Q, and the residual standard deviation, S, of each profile data were evaluated.

4.1.1 *Fitted Results of the Tangential Profile*

The profile of the tangential segment is a constructional profile, also referred to as a winter, depositional, or berm, profile (Fig. 2). In general, the fitted results plotted in Table 1 and Fig. 2 illustrate that the fitted results of these three models are much better with almost all of the correlation coefficients more than 0.95. But due to the existence of beach berm, there has a certain deviation between the fitted results from the three models and the actual subaerial topography. In comparison, with the exception of the berm zone of this profile, the fitted result from Bodge's model is optimal with correlation coefficients in excess of 0.99, and the result of Bruun/Dean's model is the worst.

Table 1 Judgment values of three fitted profiles in different coastal segments

Profiles in different segments	Model	*R*	*Q*	*S*
The profile in the tangential segment	Bruun/Dean's model	0.958	51.354	0.715
	Bodge's model	0.994	7.478	0.262
	Lee's model	0.980	24.453	0.511
The profile in the transitional segment	Bruun/Dean's model	0.895	49.148	0.756
	Bodge's model	0.945	26.266	0.553
	Lee's model	0.922	36.582	0.652
The profile in the shadow segment	Bruun/Dean's model	0.946	28.673	0.581
	Bodge's model	0.942	30.351	0.598
	Lee's model	0.968	16.725	0.443

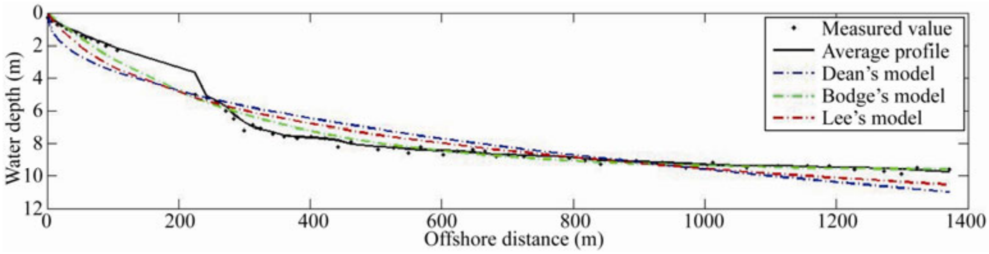

Fig. 2. Beach profile and fitted results in the tangential segment of Shuidong Bay.

4.1.2 *Fitted Results of the Transitional Profile*

The profile of the transitional segment maintains the relatively steep upper intertidal zone, but is fronted by a low gradient mid-intertidal zone with the swash bar, and then the bar and rips morphology around low tide level. At the same time, there exist multiple subdued longshore bars and troughs (Fig. 3). The fitted results plotted in Table 1 and Fig. 3 show that the fitted effects of these three models are good with almost all of the correlation coefficients more than 90%. Similarly, the fitted result from Bodge's model is obviously better than those from Bruun/Dean's and Lee's models, and Lee's model is superior to Bruun/Dean's model. Although the fitting circumstances of the profile in the transitional segment are similar to those in the tangential segment, Bogde's model is more consistent with the total profile of the transitional segment and only with the subaqueous part of the tangential profile.

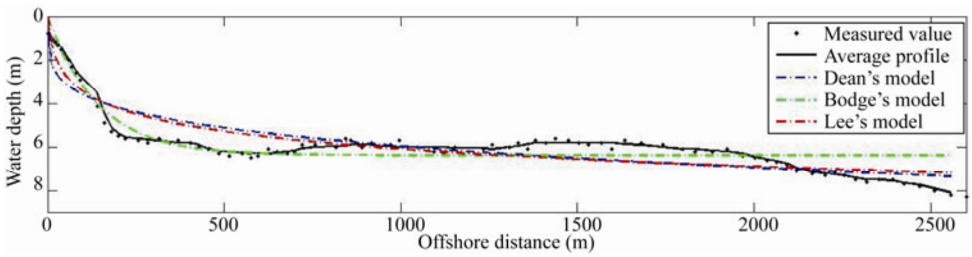

Fig. 3. Beach profile and fitted results in the transitional segment of Shuidong Bay.

4.1.3 *Fitted Results of the Profile in the Shadow Segment*

The profile of the shadow segment is characterized by a steep upper intertidal zone, flatter and more featureless subaqueous morphology without bars (Fig. 4). The fitted plot in Table 1 and Fig. 4 manifests that the fitted results of these three models are better with all the correlation coefficients more than 94%. The fitted result from Lee's model is a bit better than those from Bruun/Dean's and Bodge's models, especially within the subaqueous flatter zone. The fitted effect from Bruun/Dean's model is slightly better than that from Bodge's model. But these three models cannot fit into the actual shore portion of this profile possibly attributing to the low sea-cut scarp rearward.

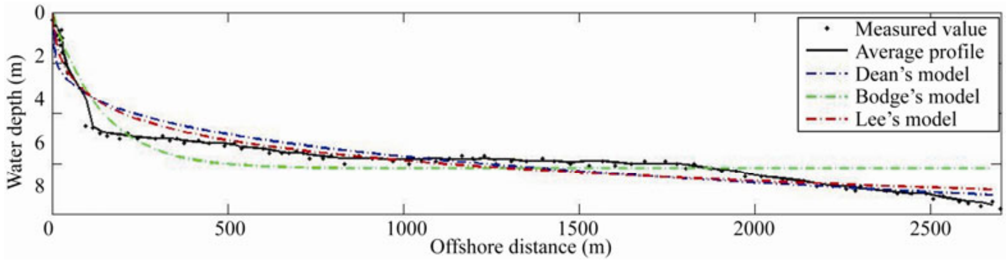

Fig. 4. Beach profile and fitted results in the shadow segment of Shuidong Bay.

4.2 Discussions

4.2.1 *Selections and Differences of the Fitted Results of Different Segments*

The fitted results of the tangential profile manifest that Bodge's model can better fit the equilibrium beach profile of the tangential segment. However, the optimal fitted effect is only limited to the subaqueous portion of the tangential profile. For the reflective beaches characterized by a berm, these three models cannot reach better results for the subaerial portion of the tangential profile, which result in some two-segment expressions presented by Bowen (1980), Inman *et al.* (1993), and Larson *et al.* (1999). Similarly, the fitted results of the transitional profile also illustrate that Bodge's model can depict the equilibrium beach profile of the transitional segment. But there exist some discrepancies for existing subaqueous bars and troughs. To resolve this problem, Wang and Davis (1998), and Hsu *et al*. (2006) presented some new shape functions to analyze the configuration of a bar-type profile. Additionally, the fitted results of the shadow profile show that Lee's model probably curve fits the equilibrium beach profile of the shadow profile. Because this beach is more dissipative and there is almost no subaqueous bar, Lee's model is an optimal selection to fit the gentle subaqueous slope zone. But because of the existence of the low sea-cut scarp on the landward portion and with a steep beach face produced by wave action, all of the fitted results from the three models have some differences compared with the actual profiles.

The selections and differences for fitting the profiles from different segments reflect varying morphodynamic characteristics of different locations in this headland-bay beach. Overall, the equilibrium beach profile from the tangential or transitional segment is more in line with Bodge's model; but Lee's model is more consistent with the shadow profile. The results basically agree with the study by Li and Chen (2009) on the Houjiang Bay in East Guangdong. However, there are a large number of headland-bay beaches in South China, whether the results in this study are applicable for other headland-bay beaches in South China or not needs further examinations. In addition, whether the equilibrium beach profiles of these headland-bay beaches have their own empirical equations or regular patterns or not requires collecting abundant profile data from various headland-bay beaches, which is currently implemented.

4.2.2 *Discussion of the Significances and Relationships of Fitted Parameters*

As illustrated in Table 2, the parameter A_1 in Bruun/Dean's model may be correlated with the sediment size. Because of the large differences between the actual profiles and those predicted by Bruun/Dean's model, Moore (1982) and Dean (1977) presented a relationship between the parameter A_1 and the grain sizes, $A_1=0.41(d_{50})^{0.94}$. As illustrated in Table 2, the values of A_1 in the tangential segment, the transitional segment, and the shadow segment are 0.492, 1.039 and 1.081, respectively. Thus, the associated sediment sizes are 0.43, 2.68 and 2.95 from the tangential segment to the shadow segment. Further, the tangential profile consisting of the coarse sand embodies the low wave energy controlling this segment. In comparison, the transitional profile made up of the fine sand reflects moderate wave energy action. Additionally, the shadow profile composed of fine sand or very fine sand shows that the high wave dominates this segment. This result agrees with not only the sediment distributions of the different segments, but also the differences of wave intensity along the different zones of this bay.

Table 2 Fitted parameters of three profiles from three models

Profiles in different segments	Fitted parameters					
	A_1	m	B	k_1	A_2	k_2
Profile in the tangential segment	0.492	0.430	9.700	0.0034	57.879	−0.304
Profile in the transitional segment	1.039	0.221	6.378	0.0071	5.612	−0.853
Profile in the shadow segment	1.081	0.241	6.195	0.0072	6.772	−0.850

The parameter m can mirror the reflectivity of the beach profiles in Bruun/Dean's model. The values of m by fitting the profiles in the tangential, the transitional, and the shadow segments are 0.430, 0.221 and 0.241, respectively. These values of m from different segments of this headland-bay beach were lower than those by Dean (1977, 1991) and Boon and Green (1988). Dean (1977, 1991) put forward that the value of m was equal to 2/3, but Boon and Green (1988) argued that the value of m was 0.5. The possible reason is that these studies abroad on the equilibrium beach profiles focus on many straight coasts. The results by fitting the beach profiles of the tangential, the transitional, and the shadow segments show that m, equal to 2/3, is not suitable for this headland-bay beach. Additionally, the "headland effect" not only affects the wave conditions and the sand distribution, but influences the value range of m. However, the values of m may clearly reflect the alongshore changes of the beach profile reflectivity. The beach in the tangential segment is open and straight, and the profile reflectivity is the highest. Under the impact of this depositional headland, wave energy in the shadow segment dissipates with the lower profile reflectivity. This discovery agrees with the studies on the Houjiang Bay in Eastern Guangdong province (Li and Chen, 2008, 2009).

The beach profile was a long-term adjustment result of wave, tide, sediment, etc. According to the analysis by Bodge (1992), the parameter B in Bodge's model was the asymptotical depth of the beach profiles which can mirror the closure depth determining the sediment movement. The values of B by fitting the beach profiles in the tangential, the transitional, and the shadow segments are 9.700, 6.378 and 6.195, respectively. That is to say, the asymptotical depths of the tangential, the transitional, and the shadow segments are 9.700 m, 6.378 m and 6.195 m. The alongshore changes of the closure depth show that the water depth under the same wave conditions resulting in the critical movement of the subaqueous sediment is gradually reduced from the tangential segment to the shadow segment, which is a further evidence that the wave energy is increasingly strengthened from the reflective tangential segment to the dissipative shadow segment.

The value of k_1 in Bodge's model characterizes the concavity of the beach profiles. The fitted value of k_1 is 0.0034 for the profile in the tangential segment, 0.0071 for the profile in the transitional segment, and 0.072 for the profile in the shadow segment. The concavity is increasing greater from the tangential segment to the shadow segment, which matches with the overall trend of beach morphodynamic states from the reflective state of the tangential profile to the dissipative state of the shadow profile.

The relationships between the parameter k_2 and the wave length in Lee's model are $k_2=2\pi/L$ and $L=gT^2/(2\pi)$, by which wave periods and wave lengths in different coastal segments can be calculated. The wave length is 20.67 m and wave period is 3.64 s in the tangential segment; the wave length is 7.37 m and wave period is 2.17 s in the transitional segment; and the wave length is 7.39 m and wave period is 2.18 s in the shadow segment. These results conform to the morphodynamic characteristics of different segments. The reflective tangential profile is characterized by coarse sand, lower wave energy, and long wave period. In comparison, the dissipative shadow profile is characterized by fine sand, high wave energy, and short wave period.

The values of A_2 in Lee's model by fitting the profiles of the tangential, the transitional, and the shadow segments are 57.879, 5.612 and 6.772, which is consistent with the gradual changing trend of A_1, m, L and T. Just as the study of Lee's work points out that A_2 may be related to the grain or other physical parameters which needs to be studied further (Lee, 1994).

From what have been discussed above, the parameters A_1 and m in Bruun/ Dean's model, B and k_1 in Bodge's model, and k_2 in Lee's model have more or fewer clear physical significances in accordance with the actual characteristics of this headland-bay beach. The differences for each parameter from the different segments are in essence correlated with the morpordynamic states of various zones.

5. Conclusions

In the present study, we studied the selections of three representative models of the equilibrium beach profile on the different segments of the Shuidong Bay – a headland-bay sandy coast after the introduction of these three models and the discussions of their application limitations, and examined the physical significances in these three models. Some interesting conclusions can be drawn as follows:

(1) The fitted results of the tangential, transitional, and shadow profiles illustrate that Bodge's model has a better ability to depict the equilibrium beach profile of the tangential or transitional segment, and Lee's model is more consistent with the shadow profile. However, whether the results in this study or the study by Li and Chen (2009) are applicable for other headland-bay beaches in South China or not needs further examinations.

(2) These three models cannot reach better results for the subaerial portion of the tangential profile, or for the subaqueous bar-trough morphology of the transitional profile, or for the landward portion of the shadow profile. The selections and differences for fitting the profiles from different segments reflect varying morphodynamic characteristics of different locations in this headland-bay beach.

(3) Most of the parameters in the three models have some clear physical significance according to the actual characteristics of this headland-bay coast. The differences for each parameter from different segments are in essence correlated with the morpordynamic states of various zones. Additionally, the physical significances of some parameters in these models still need further study.

(4) There are sparse studies on the equilibrium profile in China. In an attempt to further investigate beach morphodynamics in South China, a large number of topographic data from various headland-bay beaches are vital and should be obtained.

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