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The configuration of equilibrium beach profile in South China

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Abstract

To understand the evolution and stability of beaches, prediction of the equilibrium beach profile (EBP) is theoretically and practically important. In the present paper, a new equation, $h=Ae^{Bx}+C$ is developed to predict the change in beach profile for sections above the water level and the adjacent nearshore portions. Moreover, fractal analysis is applied to predict types of EBP for the first time using the field data collected from Liao Zuikou and Nanwan beaches, South China. Three types of EBP termed Upward-concave EBP (U-EBP), Downward-concave EBP (D-EBP) and Medium-characteristic EBP (M-EBP), are given for the studied region of South China. © 2006 Elsevier B.V. All rights reserved.

Keywords: Configuration types; Simulation; Equilibrium beach profile (EBP); Fractal analysis

1. Introduction

The equilibrium state of beach profile termed the equilibrium beach profile (EBP), where the interaction between accretion and erosion of each point of the cross-shore profile is obtained via a dynamical equilibrium, is a common feature of the coast (Komar, 1976). The concept of EBP is helpful for understanding the features of the evolution and for the stability of the beach (Kit and Pelinovsky, 1998).

An equilibrium beach profile can be applied to express a balance of destructive and constructive forces acting on the beach. If either of the destructive and constructive forces acting on the beach is altered as the result of a change in wave or water-level characteristics, there is an

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imbalance. The larger force dominates then until the evolution of the beach profile brings the forces back into balance. However, neither the complete identification nor the quantification of these individual forces is well understood (Dean, 2003). Therefore, much research on the prediction and simulation of EBP by use of field data has been done since Bruun put forward the theory of sealevel rise as a cause of shore erosion (Bruun, 1954). These research works have mainly included the use of mathematical models to predict beach profile behavior and the establishment of a series of formulas to simulate the configuration of EBP (Thieler et al., 2000).

A summary of the research related to EBP configuration is listed in Table 1.

The expression of equilibrium beach profile may be derived as (Bruun, 1954; Dean, 1977, 1991):

$$h = Ax^m \tag{1}$$

where h is the still-water depth, x is the horizontal distance from the shoreline, and A and m are empirical

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Table 1 The formulas on the configuration of the equilibrium beach profile (EBP)

Authors	Formulas	Remark
Bruun (1954)	$h = Ax^m$	Limited region of the change of the profile to the breaker zone seaward $(m=2/3)$
Dean (1977)	$h = Ax^m$	Limited region of the change of the profile seaward to the surf zone $(m=2/3)$
Bodge (1992)	$h = B(1 - e^{-Kx})$	$3 \times 10^{-5} < k < 1.16 \times 10^{-3}$
Lee (1994)	$h = B \ln(1 + x/x_0)$	
Silvester and Hsu (1993)	$h = 0.111 x^{0.575}$	The changes of the transverse distance from the crest of the bar to the shoreline
Eliezer and Pelinovsky (1998)	$h = (3Q/2e)^{2/3}x^{2/3}$	No alongshore sediment transportation
	$x + ct = \frac{2e}{c} \left(\sqrt{h} - \sqrt{2eA^{3/2}/3c} \arctan \sqrt{3ch/2eA^{3/2}} \right)$	Existed alongshore sediment transportation
Dubois (1999)	$A = ae^{-bm}$ <i>a,b</i> : experience coefficient, the relation that <i>A</i> and <i>m</i> have is some geometric function.	<i>A</i> : in relation to the size of the sediment of the sea floor.
Wang and Davis (1998)	$h(x) = A_1 x^{m1} (0 < x \le x_{tr})$ $h(x) = h_{tr} + \frac{h_{bt} - h_{tr}}{x_{bt} - x_{tr}} (x - x_{tr}) (x_{tr} < x < x_{bt})$	The range of the inner surf zone The range from the shoreward profile to the point of the broken wave.
Larson et al. (1999)	$h(x) = A_2 (x - x_2)^{m_2} \qquad (x_{bt} \le x < x_{cd})$ $x = \frac{h}{m} + \left(\frac{h}{A}\right)^{3/2} \qquad h = mx$ $h = Ax^{2/3}$	Shallow zone Deep zone
Zhang et al. (2002)	$h = \frac{m}{2} \left(\cos \frac{\pi t}{T_e} - 1 \right) + x\beta$	

**h*: the depth of whisht water; *x*: horizon distance to the shoreline; *A* and *m*: experience coefficients fitted to measured profiles; *B* and *K*: experience coefficient; *K* determines the degree of the concave of the beach profile; *Q*: transportation flux of the sediment; *t*: time.

coefficients from the fitted profile (Komar and William, 1994). The value of m is generally 2/3 (Dean, 1977, 1991). The simplicity of profile expression of Eq. (1) has resulted in its use in a variety of applications (McDougal and Hudspeth, 1983a,b; Dean, 1991; Bodge, 1992; Kit and Pelinovsky, 1998). Unfortunately, in this model, there are several shortcomings which limit its broad application. One of the main problems is its dimensionality because the units for term A in Eq. (1) depend on the value of the exponent m. Furthermore, the physical interpretation of A may be unclear (Komar and William, 1994), as are the various parameters associated with the sediment data and wave conditions of individual profiles.

In later studies, following its introduction by Ball (1967) in the analysis of edge waves, Bodge (1992) proposed an exponential beach-profile model as follows:

$$h = B(1 - e^{-kx}) \tag{2}$$

where *B* and *k* are empirical coefficients. The physical meaning of *k* in Eq. (2) can be expressed as the concavity of the profile. The values of *k* of Bodge's work range from 3×10^{-5} to 1.16×10^{-3} (Table 1). The exponent e^{-kx} in Eq. (2) can be expanded using the mathematical development of Taylor-series with an

application of the results to a typical beach profile from the Nile River Delta (Komar and William, 1994). The fitted results from Eq. (2) are closer to the measured profiles from the Hayden et al. (1975) dataset than those from Eq. (1). In addition, some researchers recommended an equilibrium profile consisting of two segments termed the outer shore segment and the inner bar-berm segment using several southern California beach profiles (Inman et al., 1993; Dean, 2003). Following Inman's work, some equilibrium models were proposed on fitting beach profiles (Wang and Davis, 1998; Larson et al., 1999).

However, the usual collections of shape functions of EBP are known to have difficulties, not only very near to the shoreline but also to the above-water portions of the beach (Wojciech et al., 2005). Owing to various dynamic actions, the response times of both the above water portions and the adjacent nearshore portions of the beach are far more rapid than that of offshore portion which is usually minor throughout the year. From an engineering viewpoint, it is more meaningful to investigate the changes of both the above water and adjacent nearshore portions of the beach than that of offshore portion. The reason is that coastal engineering is mainly located in the nearshore zone where this portion experiences frequent change.

There are also some problems in extracting EBP because it is an ideal profile. Based on the data of the changes of 504 profiles from the sites along the Mexico and the Atlantic coast in America (Hayden et al., 1975), Dean first simulated these changes of the beach profiles by fitting methods, and then proposed that the EBP formula (Eq. (1)) be adapted in the nearshore zone. The parameter *m* as an empirical coefficient is adopted in Eq. (1) (Dean, 1991). Because the fitted coefficient *m* in this case is characteristic of a normal distribution and the value of *m* is in the range of 0.2-1.2, Dean (1991) suggested that the mean value of *m* is a constant of 2/3

after fitting to the data of changes from over a hundred profiles. However, a large volume of information on the beach profiles may be lost in Dean's work and the expression of EBP formula proposed by Dean (1991) may be an unclear reflection of the shape of EBP.

EBP is an ultimate trend of the development of a beach profile which is a selective choice of the interaction between long-term erosion and accretion. From a mathematical perspective, this trend is generally called a "term expectation" (TX). The TX of the beach profile is described as the concentrated degree of the changes of the beach profile during the surveyed



Fig. 1. Studied area and measured beach profile station.

periods. Meanwhile, the mean value of the observed beach profile represents the average state of the data termed by an estimation of TX. The mean profile, which is obtained from the average of the measured data of beach profiles, can be considered as a substitute estimation of EBP. Thus, based on the view of measured



Fig. 2. The measured changes of the beach profile (lpr1–lpr13: Liao Zuikou beach profiles) (xpr1–xpr11: Nanwan beach profiles measured in half-summer year) (dpr1–dpr11: Nanwan beach profiles measured in half-winter year).



data of beach profiles in the present work (Figs. 1 and 2), the scope of the changes of beach profiles suggests that profiles vary around EBP just like a pendulum (Dai et al., 2001). Thereafter, the mean profile of each profile

was obtained, and it can be used to analyze the characteristics of the EBP.

Coastal deposition in South China is controlled by rocky headlands at the mouths of deeply incised valleys

Table 2						
Surveys	of the	beach	profiles	in	different	regions

Surveys of th	e beden promes in di	
Survey time span	Survey region	Profile establishment
1999-7-17– 1999-8-24	Liao Zuikou beach, South China	There is 13 profile established, where space distance every two profiles is 30 m.
2001-7-4– 2001-8-6	Nanwan beach, Hebao island	No.1 was established in the shadow zone, and beach profiles exposed to prevailing southeasterly swell from No.2 to No.9 were established in the central zone with a space of 50 m between each other. Furthermore, there were two profiles established in the tangential zone (No.10–11) which also spaced 50 m between each other.
2002-2-24– 2002-3-28	Nanwan beach, Hebao island	Similar to the survey stations in summer, but for the effects of several typhoons on beach, the eight stakes in the center zone were destroyed and established again in winter westwards approximately with a distance of 200 m to previous survey location.

and estuary bays (Fig. 1). Prevailing weather conditions are largely determined by an anti-cyclonic belt. Highpressure systems are periodically displaced by tropical and sub-tropical cyclonic depressions or locally modified by sea-breeze activity. The Southern China Coast is dominated by a low to moderate energy deep-water wave regime characterized by a persistent south to southeast swell. Wave climate is mild, with an average significant wave height of 1.1 m. Wave height of more than 4 m often occurs when tropical or sub-tropical cyclonic depressions pass through the region. Average tidal ranges less than 1 m are common in the Southern China coast. Due to relatively low tidal ranges, this region is largely affected by wave effects (Dai et al., 2004).

Because of the effect of a stable monsoon in East Asia, the changes in beach profiles in South China exhibit seasonal characteristics, and the appearance of the profiles are similar to "summer profile" during the summer half and "winter profile" during the winter half of the year, respectively (Komar, 1976). However, the profile in the summer half of the year exhibits an appearance similar to "winter profile" when typhoons pass across the region.

Although research on the coasts and beaches in South China started in 1980s, there is still poor understanding of the processes controlling beach profiles. Based on observed changes of the beach profiles, the purposes of the present study are to develop a new EBP model to predict the changes of the beach profile using the polynomial formula, and to discuss the types of the configuration of EBP by fractal analysis.

2. Data collection and methods

2.1. Data collection

Time series of the changes in profile were collected from two different beach environments (Fig. 1). Detailed information on the data collected is shown in Table 2. Each profile was measured over a period of

1 month. Beach surveys were conducted by the stake and horizon method (Emery, 1961). As far as the two beaches are concerned in the present paper, the appearance of first one, Liao Zuikou beach, is similar to the form of pocket beach, and is composed of quartzose sand. Here, 13 profiles were established on the beach which exhibits a reflective state (Wright et al., 1979). The other beach, Nanwan bay beach, is 4 km in length, with a quartzose sandy beach tied between bedrock headlands at Xiashui-pai point and Fengwei-zui point (Fig. 1), where the bay bathymetric contours are parallel to the shoreline. The appearance of the beach is a gently arc-shaped form (Dai et al., 2004), exhibiting a full range of morphologic states which are similar to New South Wales beaches described by Wright et al. (1979). Moreover, alongshore multi-bar patterns are present in the central nearshore zone, and terrace shoals occur on the eastern rock-wall section of the beach.

2.2. Fractal method

Fractals have been given a formal mathematical definition (Mandelbrot, 1982). Fractal theory generally describes non-linear characteristics of a system to be self-similar and scale-invariant, i.e., coastal morphology such as beach cusps repeats itself at various length scales (Werner and Fink, 1993). This implies that small pieces of the system can be magnified to obtain its structure at larger length scales (Sahimi, 2000). Thus, fractal analysis can be performed to describe the complexity, chaos and un-regulation of the geomorphology by estimating the statistical fractal dimension (D) (Feder, 1988), as defined below.

The fractal system is covered by non-overlapping ddimensional hyperspheres of Euclidean radius, r, and the number, N(r), of the spheres is counted. Therefore, for a fractal system the following equation can be given

$$N(r) \sim r^{-D} \tag{3}$$



Fig. 3. The field measured (curves) and fitted (symbol) results of the equilibrium beach profiles: lpj1–lpj13, xpj1–xpj11 and dpj1–dpj11 for equilibrium beach profile of Liao Zuikou, Nanwan (summer) and Nanwan (winter); lnh1–lnh13, xnh1–xnh13 and xdnh1–dnh13 for corresponding fitted symbols.



Fig. 3 (continued).

Table .

where \sim implies an asymptotic proportionality. Eq. (3) can be rewritten as

$$D \sim \frac{\ln N(r)}{\ln \left(\frac{-}{r}\right)} \tag{4}$$

Thus, for Euclidean objects such as straight lines, squares and spheres, we have corresponding items $N(r) \sim r^{-1}$, $N(r) \sim r^{-2}$ and $N(r) \sim r^{-3}$, respectively, and their D coincides with the Euclidean dimension. Another way of defining and estimating D is to consider a segment of a fractal system of linear dimension, L, by denoting its volume, V(L), as L is varied. If V(L) is calculated by both covering the system with spheres of unity radius, V(L) is equal to N(L), where N is the number of such spheres required to cover the system. In a fractal system, the 'box-counting method' was proposed to calculate D as follows (Sahimi, 2000):

$$N(L) \sim L^{-D} \tag{5}$$

Due to scale invariance or self-similarity of the structures of sediment in the statistical sense, the method of fractal analysis has also broadly been applied to geometrical properties of sediment grain-size (Chen and Eisma, 1995; Dyer and Manning, 1999; Andreas et al., 2003). As far as a beach is concerned, it is a deposit formed by the aggregation of sediment (Komar, 1976). The configuration of the beach profile can, therefore, be described by the scale and formation of the sediment, as a result, the beach profile can also exhibit fractal properties in the statistical sense.

Here, the measured beach profile data are analyzed to reveal the shape characteristics of the EBP in South China by the box-counting method, which is much more performable and applicable for patterns with or without self-similarity (Legendre et al., 1994).

According to box-counting method, each map with a curve of the changes in beach profile is covered by a sequence of grids with descending sizes. Then, each of the grids two values are recorded, i.e., the number of sequence boxes intersected on the map, N(L), and the side length of the squares, L. All the datapoints corresponding to N(L) and L are plotted on a log–log plot. The slope of a curve joining the datapoints, and the correlation coefficient, R, are obtained by linear regression. The value of slope of the straight line is D. However, one of the most contested questions in the application of the box-counting method is what range of

iao Zuil	tou beach					Nanwan	beach in h	alf-summer	year			Nanwan	beach in]	half-winter y	ear		
rofile	Ą	В	С	R^*	F	Profile	P	В	С	R^*	F	Profile	P	В	C	R^*	F
	-3.237	0.0246	5.628	0.993	719.5	1	3.445	-0.01228	-1.4813	0.96514	1408	1	3.914	-0.02102	-1.8503	0.926	315.03
	-5.218	0.0198	7.936	0.997	1347	2	5.2087	-0.0093	-2.547	0.98473	707.02	2	4.257	-0.01756	-1.5312	0.943	417.59
	-8.821	0.0123	11.93	0.998	3632	ю	4.2792	-0.01648	-1.437	0.96213	548.09	ю	4.226	-0.02728	-1.5613	0.891	202.42
	-5.264	0.0175	8.216	0.996	1343.3	4	4.6146	-0.01341	-1.6259	0.97472	837.25	4	4.512	-0.02204	-1.8073	0.912	258.84
	-3.304	0.0243	6.375	0.993	730.72	5	5.0563	-0.01081	-2.3793	0.9825	1224.5	5	4.812	-0.01931	-2.382	0.928	323.85
	-5.414	0.0174	8.558	0.995	1169	9	5.2036	-0.01201	-2.316	0.9778	959.37	9	4.325	-0.02745	-1.7313	0.861	150.21
	-4.206	0.0213	7.41	0.994	970.83	7	4.4854	-0.01652	-1.426	0.9617	542.82	7	4.487	-0.02541	-1.8222	0.875	169.93
	-1.463	0.0406	4.449	0.977	212.34	8	4.5853	-0.01633	-2.103	0.96442	585.53	8	4.68	-0.02357	-1.9508	0.898	218.82
						6	6.7234	-0.00744	-4.382	0.98835	1856.3	6	4.816	-0.01509	-2.3765	0.945	437.8
0	-1.927	0.0349	4.948	0.985	330.1	10	6.2502	-0.01052	-3.326	0.98442	1222.5	10	6.96	-0.00979	-4.0714	0.987	1512.9
1	-1.572	0.0386	4.573	0.978	221.64	11	27.464	-0.00173	-24.4	0.99281	2681.1	11	15.43	-0.00341	-12.495	0.995	4045.2
2	-11.18	0.0103	14.36	0.998	2905.4												
3	-31.18	0.0041	34.53	0.999	18593												
werage	-6.899	0.0221	9.909	0.992	2681.3		7.0288	-0.01154	-4.312	0.97626	1143		5.674	-0.01927	-3.0526	0.9241	732.05
R: corre	lated coeffic	sient.															

box sizes should be considered in generating the regression line in the log–log plot. This range is influenced by the range of self-similarity, the reduction factor and possible lower or upper cut-off values of the feature (Kulatilake et al., 1997). Meanwhile, most of the natural phenomena do not show the same behavior. They are characterized by only a limited range of self-similarity or self-affinity. Thus, as far as that EBP is concerned here, the valid range is determined by the number of iterations in the counting process (Kulatilake et al., 1997), which ranges from the small box size ($L_{min}=3$ m) to the large one ($L_{max}=96$ m). In the entire study area, six scales were selected to estimate the fractal value of each profile.

3. Results and discussion

3.1. Simulation of EBP

Here, the following formula is developed for EBP which can be applied to sectors both above and below the sea-water level:

$$h = Ae^{Bx} + C \tag{6}$$

where the coefficients of the equation, A, B and C are the empirical parameters.

Here, we can apply Eq. (6) to fit all the mean profiles in Fig. 3 for both above and below the sea-water level at Liao



Fig. 4. Relationships between the mean slope (m) and coefficients A, B and C.



Fig. 5. The invariance of scales of the first profile in Liao Zuikou beach.

Zuikou and Nanwan beaches. The fitted values of *A*, *B* and *C* are listed in Table 3. Generally, the efficiency of the equation can be tested by the distribution of the *F* statistic with n-2 degrees of freedom. If the *F* value in the Table 3 is larger than the theoretical *F* value in *F*-test ($F_{0.05}$ for 95% probability level), the equation can be considered to be significant. Based on the values of n=10, $F_{0.05}=4.96$ and n=50, $F_{0.05}=4.03$ at Liao Zuikou and Nanwan beaches, respectively, the regression Eq. (6) of EBP shows clear efficiency. One of the exceptions is the ninth profile in Liao Zuikou beach as shown in Fig. 3, where the down-profile sector of the berm is considerably straight.

According the results from previous research, B in Eq. (6) is similar to K in Eq. (2), which also determines the degree of beach concavity. However, owing to the surveys in Bodge's studies extending to water depths from 0 m to 10 m, the appearance of profile becomes concave-downward according to a change in K in the positive range, and it is likely to be dissipative. In such a situation, the information on the subaerial portion can be merged into the submarine portion which has relatively long cross-shore extent if surveys extend to a water depth 10 m. Thus, although data in this study extend

over only a short part of the nearshore portion, the appearance of both subaerial and submarine portions can be considered. It is seen in Table 3 that the values of *B* range from -0.0015 to 0.04 for the entire study area. It is very interesting that positive values of *B* are equal to negative values of *K* in Eq. (2). To our knowledge, a positive value of *B*, reflecting a concave-upward beach profile, has not been reported previously. This type of EBP in Liao Zuikou beach is observed first in the present paper. It is proposed that whether concave-upward or concave-downward the EBP is dominated by positive or negative values of *B*.

Moreover, some research points out that Dean's coefficient A can give a value for the profile slope (termed *m*) which increases with increasing grain size or settling velocity (Dean, 1977, 1987; Boon and Green, 1988; Bernabeu et al., 2003). Owing to the limitation of the length of beach profile surveyed here, it is difficult to conclude the meaning of fitted parameter C. In addition, all the coefficients A, B and C in Table 3 may have some relation with the mean slope *m* in each profile for Liao Zuikou and Nanwan beaches, as illustrated in Fig. 4. High values (R > 0.75) of the associated correlation coefficient (R) of a linear fitted formula in Fig. 4 suggest that the slope of the beach profile (m) has a strong relationship with all the fitted coefficients A, B and C, regardless of the various values from one beach to another. Therefore, considering that all the coefficients A, B and C are strongly related to mean slope m, Eq. (6) here can be applied to predict the change of beach profile for portions both above and below the water level.

3.2. The characteristic of invariance to different scales of EBP

The pairs of datapoints, log N(L) and log (1/L), for each mean profile, which are distributed near to the fitted lines, are considered in the present work. Fig. 5 shows only the first profile of Liao Zuikou beach. It can be seen that the EBP also exhibits characteristics of invariance to different scales. Here, scale is a unit of

Table 4

Calculated fractal values (D) of EBP by Eq. (4) at Liao Zuikou and Nanwan beach

		. ,	•												
Site	Liao Zuikou beach Na								Nanwan beach	L					
Profile	1	2	3	4	5	6	7	8	9	10	11	12	13	1–11 (half- summer year)	1-11(half- winter year)
Fractal Value (D)	1.111	1.116	1.06	1.111	1.03	1.098	1.104	1.067	1.089	1.082	1.089	1.084	1.094	1.037	1.018
Correlated coefficient (R)	0.993	0.995	0.991	0.993	0.99	0.992	0.994	0.991	0.992	0.993	0.993	0.992	0.992	0.989	0.989
The mean fractal value	1.087													1.037	1.018

I III III III III III IIII IIII IIII	8					
	Liao Zuikou	ı beach*		Nanwan beach		
Typhoon serial number	9904	9905	9908	200104	200107	Tropical depression
Influenced data	1999-07-26	1999-07-24-07-27	1999-08-19-08-22	2001-07-5-07-7	2001-07-22-07-24	2001-07-25-07-27
The biggest wind velocity (m/s)	14	15.3	22.3	11.3	7.58	13.3
The biggest wave height (m)	2.5	2.5	5.5	2.8	2.2	2.9
Main wind direction	ENE	ESE, ENE	ENE, SSE	ESE	ESE	ESE
Main wave direction	ENE	E, ENE	E, SE	ES, S	ES	ES, S

Table 5 The records of typhoons impacting on the study regions

*Dai et al., 2004.

measurement, r. The invariance characteristics of scale (r) mean that the property of researched object (i.e. configuration or degree of complexity) remains constant, in whatever way the scale changes. Considering those objects with fractal characteristics (Sahimi, 2000), the result from Fig. 5 shows that the invariance to different scales is an intrinsic attribute of the EBP.

3.3. Types of EBP

Table 4 shows the results of fractal value of each mean profile from the box-counting method. It is seen that the average fractal values of the profiles are 1.037, 1.018 and 1.087 at Nanwan beach for the summer half and winter half of the year, and at Liao Zuikou, respectively. All the fitted correlation coefficients are over 0.99 (R > 0.99).

By combining of a field geomorphologic cell and the measured data from Fig. 2, it is found that each profile of Liao Zuikou beach develops a tall berm, and that the seaward sector of the berm is concave-upward which shows reflective characteristics. According to the records of beach changes resulting from typhoon events and observations by aboriginal peoples, the configuration of the beach is similar all the time even though the typhoon acts against the beach (Table 5). Moreover, considering that the slope of beach face in Liao Zuikou beach is steep, the average slope of the all of measured profiles is 0.16 and the ratio of berm face width to the width of the convex sector (the down-profile sector of the berm) is 1:3, it is easy for the wave to propagate through the convex sector and to break on the rim of the berm. Thereafter, a tall berm formed by wave breaking and the advance or recession currents, becomes sensitive to the actions of various dynamics, such as swash, upwash, overwash and saturated action. Thus, the characteristics of the reflection of the Liao Zuikou beach are intensive (Wright and Short, 1984). Similarly, the average slope values of the Nanwan beach in the summer and winter halves of the year are 0.04 and 0.05, respectively. Meanwhile, the energy of the incoming wave located at the shoreline is weak as a result of the buffering effects of the sandbar and long-distance

propagation in the surf zone. Thus, the fractal values of EBP at Nanwan beach in either the summer or winter halves of the year are smaller than those at Liao Zuikou beach. Obviously, the wave energy at Nanwan beach is naturally low, which results in a fractal value. In addition, the fractal value of EBP in the summer half of the year is higher than that in the winter half because of several typhoons acting on the beach during summer (Table 5).

Based on the above relation, the configuration of EBP in South China can be divided into three types as shown in Fig. 6. Here, these three types are termed as Upwardconcave EBP (U-EBP) reflecting tall berms, steep slopes of the beach face and large fractal values; Downwardconcave EBP (D-EBP) reflecting no berm, gentle slopes



Fig. 6. Three types of equilibrium beach profiles: U-EBP (a), D-EBP (b) and M-EBP (c).

of the beach face and small fractal values; and Mediumcharacteristic EBP (M-EBP) reflecting berms whose sector above the water level is concave-upwards and the sector below sea-level is concave-downwards, and have medium beach face slopes and medium fractal values.

From this study, it is noted that the fractal value of each profile was an estimated value from linear regression. The accuracy of these estimated fractal values could be influenced by both the box range used for the regression and the value of the reduction factor in the box network (Kulatilake et al., 1997). Although all the fitted correlation coefficients are over 0.99, it is limited by the fact that only six scales were selected to estimate the fractal value of each profile due to the short cross-shore extent of the measured beach profiles, which may result in reduction in the accuracy of the fractal value of each profile.

4. Conclusions

Based on previous studies and field data collected from two beaches in different morphodynamic states in South China through fractal analysis and mathematical simulation, some meaningful conclusions are as follows:

- An exponential equation adapted to EBP in South China is developed as h=Ae^{Bx}+C, where three parameters are empirical coefficients, namely, A, B and C. The value of each coefficient can be determined by the slope (m) of the beach profile.
- (2) The invariance to different scales is an intrinsic attribute of the EBP.
- (3) The configurations of EBP in South China are divided into three types:
 - U-EBP. The appearance of EBP presents a concave-upward state. Its beach face slope is steep and has a large fractal value. This type of EBP develops high berms.
 - D-EBP. This profile presents a concave-downward state, but the berm has not formed on the beach. Its beach face slope is gentle and has a small fractal value.
 - M-EBP. The beach develops berms whose sector above sea-level is concave-upward and the sector beneath sea-level is concave-downward, and has medium beach face slopes and medium fractal values.

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