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Beach Cusps and Beach Dynamics : A Quantitative Field Appraisal

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ABSTRACT

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The physical expression of beach cusps during the process of beach dynamics defines the objective of this report. A total of 93, largely fortnightly, volumetric beach change observations under cusp existence and extinction phases have been employed for this purpose. The above data were assessed alongside existing information on linear beach changes during both cusp phases from the study area. The study area is a 3 km long, moderate-high energy sandy beach fringing the southeast Atlantic coast of Nigeria. In the main, cusps are prone to develop during milder coastal conditions. In relation to the three principal beach states (dissipative, intermediate and reflective)[1] cusp formation and persistence were most significant on beach sectors exhibiting reflective process signatures. However, in contrast to previous postulates, cusp development and disappearance phases did not reveal any unique relationship with the direction of volumetric beach change. The cusp phases correspond better with linear beach changes. Between 90-95% of the volumetric accretionary events during both cusp phases progressed through beach response routes characterized by beach scarp stability. Erosional events indicated a wider spread of response routes. It is asserted that on dissipative beaches, cusps play a passive role in the overall process of volumetric profile adjustment. The converse may be the case on highly reflective beaches.

INTRODUCTION

Beach cusps are sinusoidal geomorphic features on non-rocky coasts. A considerable body of data on geological and engineering perspectives pertaining to the origin, nature and characteristics of beach cusps have been detailed from a wide range of localities in the literature. The sequence of thoughts on beach cusps is illuminated in the reports and references cited by Guza and Inman

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[1]Wright and Short (1983).

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(1975), Dubois (1978), Sallenger (1979), Inman and Guza (1982), Takeda and Sunamura (1983), Kaneko (1985), Seymour and Aubrey (1985), and Antia (1987b).

Only a few investigators, for example, Kana (1977), Dubois (1978), Short (1978), Takeda and Sunamura (1983), and Antia and Nyong (1986) have actually commented on the possible application of the knowledge gained through beach cusp studies to the phenomenon of beach erosion and accretion. Unfortunately, the relationships between the phases of cusp development and disappearance and beach dynamics detailed in the above reports were either theoretical, qualitative or marginally quantitative in approach. A somewhat quantitative but time-limited study of cusp–beach response during a storm event was reported by Eliot and Clarke (1986).

This author is of the opinion that results of systematically-obtained field data on beach changes under the different cusp phases over a prolonged period of time is more beneficial to coastal engineering practice. This conviction, contrary to the aforementioned study approaches, defines the objective of this investigation.

STUDY SITE AND PROCEDURES

The study site (Fig. 1) is a 3 km long, east–west oriented sandy beach on the southeastern Atlantic coast of Nigeria. Locally referred to as Ibeno, the beach

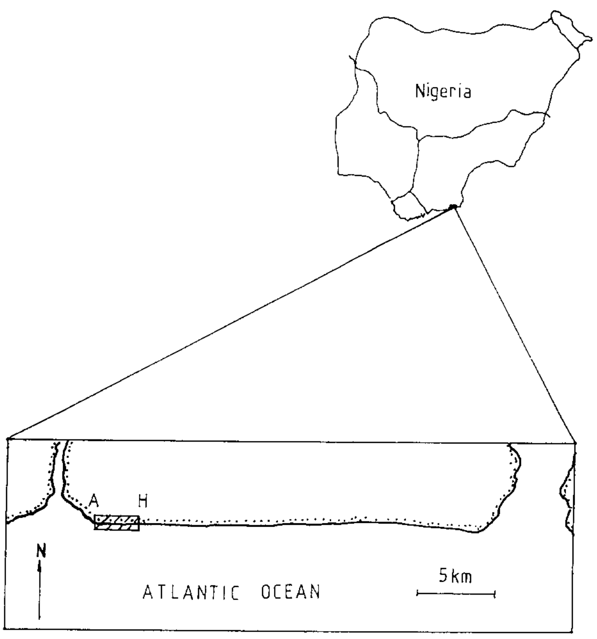

Fig. 1. Location of study site A–H.

is constituted mostly of fine-grained sediments. Mean grain size however varies between 0.18–0.34 mm. The beach foreshore gradient is typically in the 1–6 degree range.

Tides are semi-diurnal and have amplitudes of 3–4 m. Modal wave height range is 50–100 cm while the wave period varies typically between 6–15 s. Winds are predominantly southwesterly with a modal velocity of 5–10 m s^{-1}. Longshore currents have a net easterly direction and modal velocity of 0.4–0.6 m s^{-1}. Further details on the coastal oceanographic processes of the study area are presented in Antia (1989).

The study area was divided into eight sectors which were sequentially designated A to H in the eastward direction. As observed in the aforementioned study, most of the coastal oceanographic processes revealed no significant alongshore differences between the beach sectors. One notable exception was the frequency of the breaker pattern. In general, wide surf zones with many shore-parallel bars such as at beach sector A showed a lower plunging–spilling breaker ratio than the narrow, barless surf zones fronting the beach sectors G and H.

At each of the beach sectors, profile changes were monitored predominantly fortnightly between July 1984 and November 1986. A careful inventory of cusp existence and extinction was made alongside the topographic surveys. The methodology for the latter is detailed in Emery (1961). Through superposition of succeeding profiles, volumetric rates (m^3 per m of beach length per given time interval) and direction (accretion or erosion) of beach change were determined. Linear beach changes were evaluated based on the shifting position of the berm edge in relation to established backshore reference stakes.

Through continuous measurement of beach scarp height and adjacent foreshore slope, nine possible routes of beach response associated with cusp phases were established as previously outlined in Antia (1987a). As presented in Table 1, a response route is defined by a specific combination of variation and/or stability in beach scarp height and beach foreshore slope. Changes in the dimensions of the above mentioned geomorphic elements over successive time intervals are considered a "variation" when differences in dimension equal or exceed 20% of the antecedent values. Alternatively, "stability" designates either no change in dimension (i.e. "the same values") or changes in magnitude lesser than 20% of the antecedent values. In this respect, beach response route 1 implies that the beach has been subjected to processes culminating in a higher scarp height and increased foreshore slope, the variations being at least 20% greater than the pre-existing dimensions.

Cusp events were further assessed in relation to the beach state classification of Wright and Short (1983). The three principal beach states of the latter, i.e. dissipative, intermediate and reflective, are delineated on the basis of the surf-scaling or reflectivity parameter, ϵ. This dimensionless parameter is derived from the relation:

TABLE 1

Definition of nine beach response routes and frequencies of the direction of volumetric beach changes (%) in relation to the routes and cusp phases

ROUTES	1	2	3	4	5	6	7	8	9
new scarp height	H	H	L	L	S	S	H	L	S
new foreshore slope	I	D	I	D	D	I	S	S	S
BEACH CHANGE									
(A) with cusps (%)									
$n=44$	2	7	2	7	27	30	2	2	21
(A1) erosion									
$n=24$	4	8	4	13	25	25	4	4	13
(A2) accretion									
$n=20$	-	5	-	-	30	35	-	-	30
(B) without cusps									
$n=49$	4	2	6	2	33	31	2	-	20
(B1) erosion									
$n=29$	7	4	7	4	38	24	-	-	17
(B2) accretion									
$n=20$	-	-	5	-	25	40	5	-	25

Notes: H = higher; L = lower; I = increase; D = decrease; S = same (variation in dimension <20% of pre-existing value).

TABLE 2

Reflectivity (mean $\bar{\epsilon}$ and standard deviation, σ_ϵ), and frequency of cusp occurrence (%) at the beach sectors

sector	$\bar{\epsilon}$	σ_ϵ	cusps (%)
A	54.7	75.7	17
B	21.3	26.4	27
C	13.1	15,6	50
D	29.5	43.3	60
E	47.9	45.1	33
F	27.9	31.1	27
G	15.7	12.5	85
H	15.4	14.1	82

$$\epsilon=\frac{H(2\pi/T)^2}{g(\tan\phi)^2}$$

where H is breaker height (m), T is wave period (s), g is acceleration due to gravity (10 m s^{-1}) and ϕ is beach/surf zone gradient in degrees.

The end-member beach states of this classification scheme, i.e. reflective and dissipative, are attained at $\epsilon \leqslant 2.5$ and $\epsilon > 33$, respectively. The mean and standard deviation of ϵ (i.e. $\bar{\epsilon}$ and σ_ϵ) presented in Table 2 are based on at least 20 time-series observations made at each of the beach sectors in the course of cusp inventory. Additional details on many aspects of cusp characteristics, as well as ϵ values from the study area, are presented in Antia (1987a,b).

RESULTS AND DISCUSSION

Beach cusp development and disappearance have been intimately related to the sequence of beach accretion (berm-building) and retrogression (Dubois, 1978; Short, 1978; Takeda and Sunamura, 1983). Subsequent discussion of field-acquired data examines the generality of the above postulates.

Ninety three cusp and volumetric beach change observations were made from the beach sectors. Cusps were in existence in 44 (47%) of the cases and extinct in 49 instances (53%). The distribution of the observations was such that 74% occurred during storm coastal conditions (May–October), and 8% and 18% during calm (November–January) and transitional (February–April) coastal conditions, respectively.

Because the bulk of the observations were made during storm conditions, the storm seasonal trend for each of the cusp phases at the beach sectors was evaluated and depicted in Fig. 2. It can be noted that each cusp phase in Fig. 2 is considered as a separate or exclusive event. The per cent sum of the three seasonal components at a given beach sector for a given cusp phase equals 100.

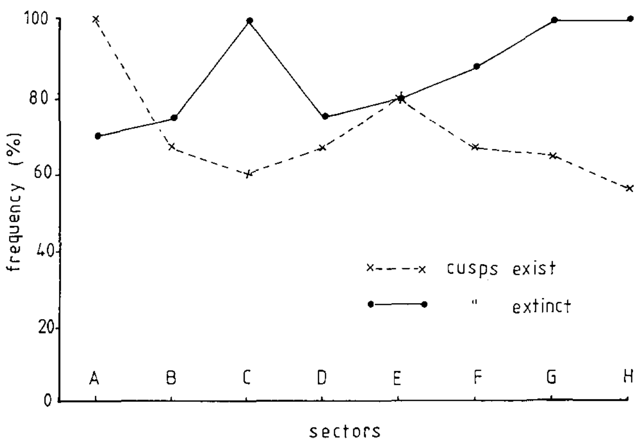

Fig. 2. Storm season frequency trends within the cusp existence and extinction phases at beach sectors A–H.

It can be clearly seen from Fig. 2 that the storm seasonal trend for the cusp existence phase showed a reduced frequency when compared with the extinction counterpart.

The above observation is in agreement with previous assertions, (e.g. Russell and McIntire, 1965; Antia, 1987b). These authors reported that cusp existence seems to be enhanced during the transition from high-energy to low-energy conditions. Approximately 76% of the seventeen observations made during the transitional coastal condition were characterized by cusps. The frequency of cusp–beach change observation during calm coastal conditions is unfortunately too low to allow any statistically-significant inference to be made.

Of the 44 instances during which cusps were encountered, 55% of the cases were associated with erosional (volumetric) profile changes, against 45% with accretional volumetric changes. These results imply in essence that, contrary to the suggestions of previous workers, beach cusps may not be a reliable indicator of the direction of volumetric beach change. This stems from the fact that cusps may exist under different coastal conditions with which they are in equilibrium. The process signatures of such coastal conditions may ultimately dictate the direction of the volumetric beach change.

An important question, not directly assessed in the present investigation, is the passive or active role played by cusps in course of the overall profile volume change. Two main gaps in the knowledge may account for the present non-conclusive role of cusps during beach dynamics. The first is the non-quantitative nature of morphological changes associated with beach cusps reported in the literature. It is well known from studies (e.g. Short and Hesp, 1982) that morphological changes on beaches may progress without significant changes in the overall profile volume.

The second constraint is related to the dearth of data on cusps and profile change during non-storm conditions. The bias in data spread may be remarkable considering the fact that in response to the changing coastal conditions, certain beaches may reveal cusps of different characteristics and at different beach levels (Antia, 1987b, 1989). Ibeno Beach was, however, consistently characterized by a single level of cusps extending from the berm edge seawards.

From the average volumetric beach change data given in Table 3, it is observed that the overall mean value for erosion during the phase of cusp existence of 3.5 $m^3 m^{-1}$ per fortnight was about 30% higher than the cusp extinction phase. The latter result would seem to imply that cusps have the potential to accelerate beach erosion. Kana (1977) noted that horns of beach cusps often cause the formation of beach scarps. Beach erosion as a consequence of swash incursion is known to be most efficient after scarp formation.

The generality of the above assertion is yet to be fully established from prolonged, year-round data. Kana's observations were limited to a storm period. In the same respect, the data employed in this report show a storm season bias. However, further inspection of Table 3 reveals that the mean volumetric ac-

TABLE 3

Average beach changes ($m^3\ m^{-1}$ beach length per fortnight) at the beach sectors in relation to phases of cusp existence and extinction

sectors	erosion		accretion	
	with cusps	without cusps	with cusps	without cusps
A	5.0	4.6	-	3.8
B	1.2	4.4	-	1.1
C	5.4	0.4	3.7	3.3
D	1.1	2.0	1.9	2.4
E	5.3	1.8	5.3	2.1
F	1.0	2.0	1.3	2.5
G	4.4	0.9	2.4	-
H	4.6	3.8	2.7	0.7

cretion rate was of the order of 22% higher during the cusp existence phase than during the cusp extinction phase.

Therefore, the higher values of mean volumetric beach erosion and accretion during the cusp existence phase in relation to cusp extinction phase is suggestive of the passive role of cusps in determining the direction of volumetric beach change. This is particularly the case on beaches with modally dissipative and, to some extent, intermediate beach-state processes. A major distinction in process signature of the end-member beach-states of Wright and Short (1983) is the predominance of infragravity standing oscillations under dissipative conditions as against standing subharmonic oscillations under reflective conditions.

Further insight on the possible physical expression of cusp existence and extinction in relation to beach dynamics entailed examination of their distribution frequency as a function of the mean reflectivity parameter, $\bar{\epsilon}$ (Table 2). Correlation between both variables shown in Fig. 3 indicates that cusps are more prone to develop under increasingly reflective beach conditions (i.e. lower values of ϵ). The correlation coefficient, r, was -0.7 for both $\bar{\epsilon}$ and σ_ϵ. In the latter case, the implication is that cusps require a high stability in environmental conditions in order to exist or persist. The variables X and Y of the regression equation shown in Fig. 3 represent cusp existence frequency and reflectivity, respectively.

Reports of Wright and Short (1983) indicate that reflective beaches have a high erosion sensitivity primarily because of the accentuated wave run-up and ease of berm cutting with the onset of moderate energy long-period swell. The latter enables the subharmonic oscillations at the beach to attain amplitudes greater than those of the incident waves. On the other hand, the predominance and persistence of cusps on beaches of high reflectivity have been reported by

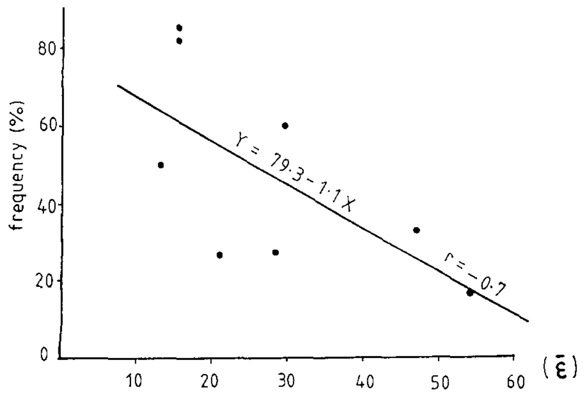

Fig. 3. Relationship between frequency of cusp existence and mean reflectivity parameter values at the beach sectors.

Inman and Guza (1982) and Antia (1987b). These authors argue that cusps on reflective beaches owe their origin and widespread character to the easily excited subharmonic edge waves.

From the aforementioned, it can be easily conceptualized that beach cusps should express a retrograding state of a beach. The latter trend was observed in a study by Antia and Nyong (1986). However, linear beach change data (based on berm edge migration) was employed for the above mentioned study. The bulk of the data on which the latter is based are presented in Antia and Nyong (1988). Of the 33 instances of cusps noted, 19 (58%) were associated with values of $\epsilon \leqslant 10$; only 9% of the cusps were associated with $\epsilon > 30$. About 79% of cusps occurring in the $\epsilon \leqslant 10$ range were associated with beach erosion, the linear rate being typically $\leqslant 10$ m per fortnight.

The above presented results suggest that cusps may better predict the direction of linear, as opposed to volumetric, beach change and corroborate the fact that wave run-up and associated berm cutting may play a leading role in cusp formation. The above reflective beach signatures may occasionally occur at the study area during high tides when the steeper portions of the beach profile are inundated. It is however recognized that wave run-up may occur during high tidal conditions without cusp formation on dissipative beaches. This would rarely be the case on reflective beaches. Since linear beach change depends very much on the position of the berm, it is to be expected that cusp existence arising from berm cutting would normally indicate linear beach erosion.

Contrary to the above, sediments derived from berm cutting may merely be redistributed within the profile such that cusps may form without a corresponding change in either the magnitude or the direction of the profile volume.

The phases of cusp development and disappearance in relation to the beach response routes given in Table 1 indicates no obvious distinction. However, it should be noted that 90–95% of the volumetric accretionary events, during both phases of cusps, proceeded through response routes 5, 6 and 9. These routes are all characterized by relative stability in beach scarp height over time whereas the slope may vary. On the other hand, erosional events under cusp phases showed a wider spread between response routes. Routes 5, 6 and 9 accounted for 63 and 79% of the volumetric erosional events during cusp existence and extinction phases, respectively.

The lack of distinct partitioning in response routes between the cusp phases noted above is further suggestive of the fact that cusps are passive elements in the process of beach profile volume change. This is particularly true for modally dissipative-intermediate beaches ($\epsilon > 2.5$). From the trend in the results in Fig. 3, there is a compelling reason to suggest that beach cusps would serve as a better predictor of beach dynamics under beach state conditions approaching that of high reflectivity ($\epsilon \leqslant 2.5$).

CONCLUSIONS

The quantitative field appraisal of beach cusp and beach change relationship leads to the following conclusions:

(1) Beach cusp development is enhanced under milder coastal conditions and on beaches with reflectivity parameter values approaching the domain of a high reflective beach state.

(2) Volumetric estimates of beach erosion and accretion did not exhibit a predictable relationship with the phases of cusp existence and extinction. This is primarily because sediment transfer processes during cusp formation are surbordinate to other processes such as longshore and rip currents with much higher sediment transfer capacity. Moreover, relative to the entire beach profile, cusps may be considered a local feature. It therefore follows that any quantity of sediment extracted from the beach profile during cusp formation can be redistributed to other parts of the profile. On the other hand, using berm edge position as a reference, the cusp phases reveal better association with linear changes in beach width.

(3) Volumetric erosion and accretion rates were 22 and 30%, respectively, higher during the cusp existence phase than during the extinction phase.

(4) Beach response routes 5, 6 and 9, all of which are characterized by relative stability of beach scarp over time, accounted for over 90% of the volumetric accretionary events during the cusp existence and extinction phases as against 63–79% of the erosional events.

(5) The role of cusps in beach change phenomena depends on the beach state : active on reflective but passive on dissipative beaches.

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