CHAPTER 61

BEACH CUT IN RELATION TO SURF ZONE MORPHODYNAMICS

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Sydney, N.S.W. 2006. Australia

ABSTRACT

Field experiments on the coast of Southeastern Australia, supplemented by systematic observations in a variety of environments in other parts of the world, indicate at least three quasi-discrete modes of subaerial beach cut, each of which is related to a distinct set of mechanisms. For any given set of incident wave conditions, the operation or non-operation of a particular mode of cutting depends on the morphodynamic state of the surf-zone and beach. Steep, reflective beaches are susceptible to cut under moderate swell conditions by accentuated runup and berm overtopping associated with subharmonic resonance. Appreciably more energy is required to cut flat dissipative beaches. Cut of dissipative beaches involves high setup which oscillates at infragravity frequency and allows the bores of broken waves to penetrate to the backshore. Beach states intermediate between the reflective and dissipative extremes are subject to cut by both the modes just described as well as by scour in the embayments of topographically arrested rips which can cause significant localized erosion even when the coast regionally is accreting. Beaches which most commonly exhibit intermediate topographies are the least stable and most mobile.

INTRODUCTION

Most recent studies of beach stability and problems of beach erosion versus accretion have focused either on sediment budget imbalances related to littoral drift or on onshore-offshore sediment migration and associated "cyclic" or seasonal changes in beach/inshore profiles. Prominent examples of the latter include studies of the critical conditions responsible for the shift in beach profile from the accreted "swell" (or "summer") profile to the erosional "storm" (or "winter") profile (e.g. Komar, 1976); Davis and Fox, 1972; Sonu and James, 1973; Winant et al., 1975).

Some valuable successes have been attained in predicting the likelihood of sediment moving offshore versus onshore over simple beach topographies in terms of critical wave steepness, sediment fall velocity, and beach slope (Dean, 1973; Hattori and Kawamata, 1980; Sawaragi and Deguchi, 1980). However, criteria which take account of pre-existing complex three dimensional or bar-trough beach and surf zone topographies, such as prevail in Southeastern Australia, do not yet exist and quantitative predictions of the direction of beach change are far from straightforward. Furthermore, it is impractical to address the problem simply in terms of shifts between extreme "swell" and "storm" profiles since either extreme or intermediate topographies may be arrested by environmental conditions for extended periods and since the "cyclic" alternation between extremes often requires several years to complete (e.g. Thom & Bowman, 1980).

From the point of view of most coastal engineers concerned with beach protection the most immediate threat to beaches is manifest as subaerial beach cut. There appear to be at least three quasi-discrete modes of beach cut, each of which is related to a distinct set of mechanisms. For any given set of incident wave conditions, the operation or non-operation of a particular mode of cutting depends on the morphodynamic state of the surf-zone and beach. The morphodynamic state is in turn, dependent partially on stage in an erosional or accretionary cycle and partially on local environmental conditions. Because the mechanisms controlling each mode are different, identical incident wave conditions may cause erosion in one situation while causing accretion in another. The erosion "hazard" associated with any given beach, as well as beach mobility as expressed by the range or standard deviation of shoreline positions over an average year thus depend on the modal or most prevalent morphodynamic state of the beach and surf zone.

This paper, is aimed at elucidating, qualitatively, three aspects of the beach erosion and beach stability problem: (1) What are the major modes of subaerial beach cut and how do they depend on the morphodynamic state of the beach and surf zone? (2) What surf-zone processes may act to determine the possible seaward transport of the eroded material to the outer surf zone and hence aggravate the severity of erosion? (3) What is the consequent relationship between relative erosion hazard, beach mobility and morphodynamic state?

The concepts and examples presented have been synthesized from an extensive set of direct field observations on the high wave energy, microtidal coast of Southeastern and Southern Australia. Many of the beaches examined are strongly compartmented and all are dominated by shore-normal rather than longshore sediment exchange. Our experiments have involved beach surveys, repeated and time lapse photography, and direct measurements of surf-zone pressure and current time series. The various methods employed are described by Bradshaw et al. (1978), Wright et al. (1979a & b), and Short (1979, 1980).

MORPHODYNAMIC STATES AND MODES OF CUT

The likelihood of a particular mode of cut occurring on a beach, for example with increasing wave height, depends on the morphodynamic state that the surf zone and beach are in at the time. Wright et al. (1979a & b) recognise at least six different states, each of which is distinguished by a different association of morphology, circulation, surf behaviour, and resonant frequencies. Short (1979a & b) has shown how different morphologic types relate to stages in erosional accretionary sequences or "cycles". The two morphodynamic extremes are : (1) steep reflective beaches with narrow surf zones; and (2) dissipative, flat beaches with wide, barred surf zones. (3) Between the two extremes are several intermediate types of bar-trough and "rhythmic" inshore topographies including alternating transverse bars and rips. The reflective state is characterized by maximum storage of available sediment within the subaerial and intertidal part of the beach and is equivalent to the "swell" (or "summer") profile whereas the dissipative state is equivalent to the "storm" (or "winter") profile with most of the sediment stored subaqueously in the surf zone. As in the "classic" beach cycle models, the reflective and dissipative extremes represent respectively the accrectional and erosional end points. However, different sets of environmental conditions can cause one or the other of the extremes to prevail virtually year round as the modal state or may favour the prevalence of intermediate states.

Each beach state presents its own distinctive erosion "hazard" both in terms of the probability of erosion and in terms of the most likely mode of cut. In the immediate time frame the "instantaneous" beach state, which depends in part on antecedent processes, determines the day-to-day sensitivity of the beach to short term increases in wave energy. Over the long term, the modal beach state and range of states determine the annual probability of cut for any given wave climate as well as the mobility of the beach (see Short, 1980 for a discussion of beach mobility). Table 1 summarizes the characteristics and causes of the three primary modes of beach cut together with their relationships to morphodynamic conditions. Figure 1 illustrates the major plan and profile configurations of

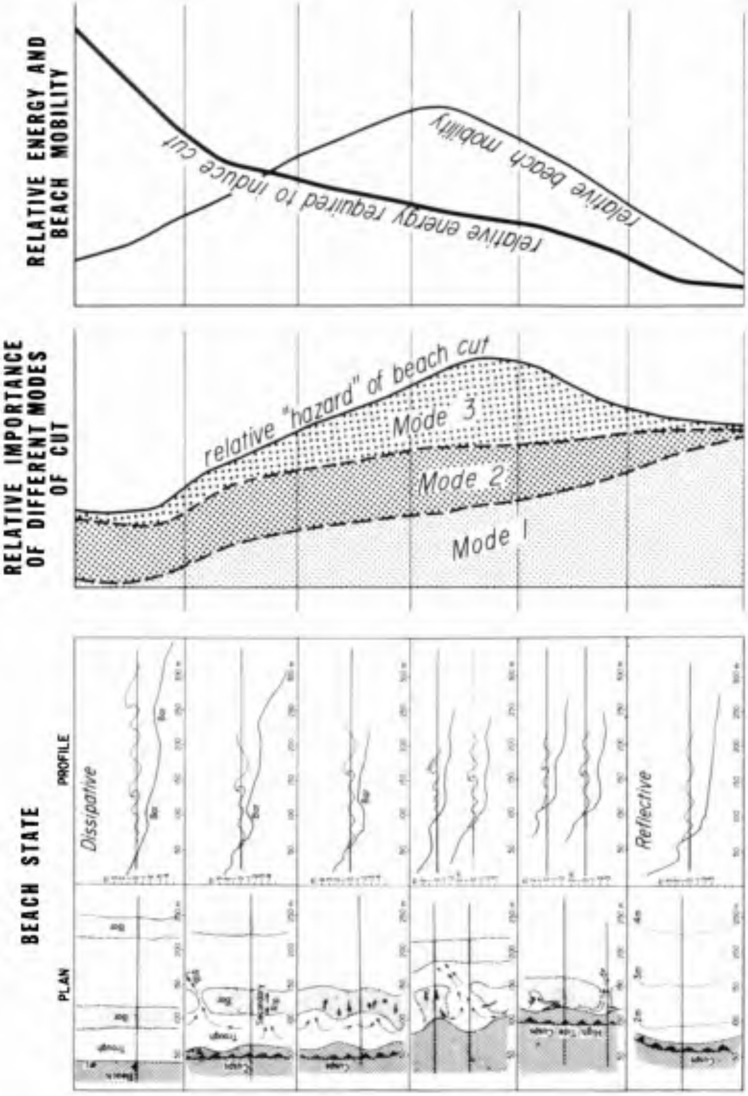

Figure 1: Characteristic Beach States an' associated Modes of Beach Cut and Relative Erosion "Hazard".

the extreme and intermediate beach states and indicates the relative erosion hazard and relative importance of each mode of cut corresponding to each state. The relative wave energy required to induce erosion and relative beach mobility for modal states are also indicated. As Figure 1 suggests, Mode 1 cut is probably the most important mode of cut on reflective beaches but is suppressed on extremely dissipative beaches where it is replaced by Mode 2 cut. Beaches in intermediate states are susceptible to cut by both Modes 1 & 2 as well as by Mode 3.

Table 1: Modes of Beach Cut in Relation to Beach State.

	MODE OF BEACH CUT	CAUSE	ASSOCIATED BEACH & SURF-ZONE CONDITIONS	RELATIVE ENERGY REQUIRED TO INDUCE BEACH CUT
1	Accentuated runup and berm overtopping, formation of erosional cusps	Strong subharmonic resonance	REFLECTIVE	LOWEST
2	Backshore scarping by bores superimposed on long-period setup oscillations	Strong infragravity oscillations	DISSIPATIVE	HIGHEST
3	Beach scarping in embayments of arrested rip cells	Radiation stress gradients induced by irregular surf-zone topography	INTERMEDIATE, RHYTHMIC Surf-zone topography, regions adjacent to shoreline protrusions, inlets or river mouths.	INTERMEDIATE

CUT OF REFLECTIVE BEACHES

The steep reflective beach states tend to prevail in highly indented compartments, in the protected lee of headlands, in the presence of coarse material, or at the "end points" of prolonged accretion. On the New South Wales coast, they are particularly common at the low energy (southern) ends of spiral (or "zeta curved") embayments. Storage of active sand is primarily in the intertidal and subaerial beach rather than in the surf zone or nearshore and relatively deep water reaches to the base of the intertidal beach. The surf-zone is narrow or nonexistent and waves surge up the beach face with maximum runup (relative to incident wave height).

Near the beach, oscillations tend to be standing at a range of frequencies. A prominent feature of the hydrodynamics of reflective beaches is subharmonic resonance. There is now considerable evidence indicating that these subharmonic oscillations are edge waves (Huntley and Bowen, 1975; 1979; Wright et al., 1979a & b). Furthermore, field data (Wright et al., 1979a & b; Wright, in prep) suggest that, so long as the reflective condition is maintained (i.e. steep beach, low-steepness waves), increased wave energy will increase the amplitude near the beach of the subharmonic resonance. Runup maxima under these conditions are strongly dominated by the subharmonic motion with the result that alternate swashes reach extreme elevations on the beach. Typical power spectra of water surface oscillations on a reflective beach (Bracken Beach, south of Sydney, see Wright, et al., 1979b) are shown in Figure 2. These spectra are based on observations made under moderate energy conditions (breaker height, H=1.5 metres) and clearly show a pronounced subharmonic peak which exceeds the incident wave peak over the step at the base of the beach (inner station).

The growth of subharmonic resonance on steep beaches under conditions of long-period swell is a major cause of the first mode of beach cut (Table 1). This mode is characterized by accentuated runup and berm overtopping (Fig.3) accompanied by strong seaward pulsing at subharmonic frequencies below the base of the beach. During the early phases, liquifaction and slumping of the beach face takes place in the mid and low swash zone while large erosional cusps develop on the upper beach with maximum scour occurring in the cusp bays.

Since subharmonic resonance is most easily excited on reflective beaches and requires the least energy to excite (Guza and Davis, 1974; Guza and Bowen, 1977) reflective beaches are most sensitive to Mode 1 erosion under the wide range of energy conditions. Probably for this reason it is common, on the New South Wales coast for moderate, long swell to cut reflective beaches while promoting accretion on nearby dissipative beaches. Provided energy conditions are not severe, cut ceases once reflectivity has been sufficiently reduced to reduce resonance and runup. Conversely, accretion normally ceases once maximum reflectivity has been attained. In strongly embayed compartments where the reflective beach represents the modal state, beach mobility thus tends to be low.

Inshore circulation seaward of modal reflective beaches is normally weak or nonexistent (Wright et al., 1979a) and, although subaerial cut may be severe, the eroded sand is not normally transported very far offshore except when the erosive conditions persist long enough to alter the state

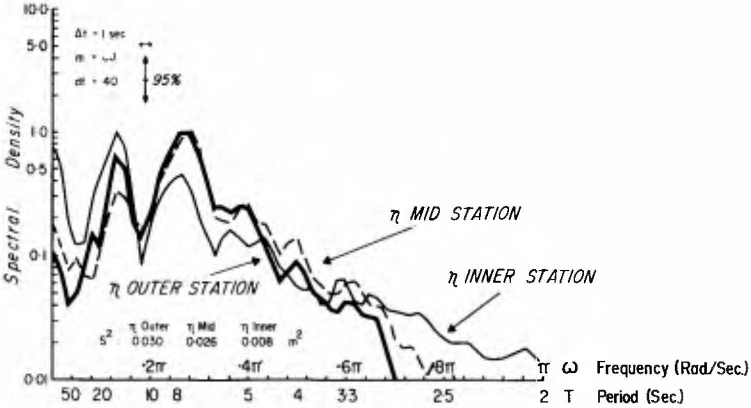

Figure 2: Typical power spectra of surface elevation (η) and shore-normal current (u) from a reflective beach. Note the pronounced subharmonic peak. (Bracken Beach, 10 Dec. 1977).

Figure 3: Accentuated runup, berm overtopping, and the initiation of erosional cusps on a reflective beach under conditions of long-period, moderate energy swell (Bracken Beach).

of the beach significantly. However, an exception exists for reflective beaches which prevail at the protected southern ends of spiral embayments. Large, relatively strong rips frequently develop in these localities under moderate to high energy conditions. Some prominent examples include Cronulla, Dee Why, and Palm beaches near Sydney. These rip systems increase the severity of erosion when it occurs.

CUT OF DISSIPATIVE BEACHES

On exposed time-varying beaches the extreme dissipative state occurs following severe erosion. The dissipative state may also be arrested as the modal state in localities exposed to persistent high-energy waves or when there is an abundance of fine-grained sediment in the inshore. Along deltaic coasts dissipative conditions commonly prevail even with relatively low wave energy.

An example of a perennially dissipative beach in New South Wales is the northern section of Seven Mile Beach, 150 km south of Sydney where fine sand, drifted northwards accumulates in an exposed inshore zone. An even more prominent example is found along the Coorong coast of South Australia where a long straight dissipative beach extends from Goolwa 190 kilometres to the southeast (Fig.4). Goolwa's high energy dissipative state is maintained by long period southwesterly swell with heights which persistently exceed 3 metres combined with a sediment suite consisting of fine carbonate sands. Both Goolwa and Seven Mile Beach exhibit wide surf zones with multiple parallel bars and negligible rip circulation. The Goolwa surf zone is normally 500 metres or more wide.

The flat profiles and high turbulent viscosities of the dissipative extreme preclude Mode 1 cut since subharmonic resonance and standing oscillations at incident wave frequencies are suppressed and runup is very low relative to breaker height. In fact, dissipative beaches generally have a greater probability of accreting than they do of eroding. Nevertheless, dissipative beaches may erode under high energy conditions although this erosion often consists solely of backshore scarping without consequential removal of sand to seaward of the foreshore. Neglecting the effects of non-wave-induced water level rises, (e.g. storm surges, extreme tides), cut of highly dissipative beaches primarily involves the second mode of cutting (Table 1). Pronounced setup on the landward margins of flat dissipative inshore profiles increases the effectiveness of return flows and may, under conditions of high energy or steep waves, allow the bores of broken waves to penetrate to the backshore or to the foredune base where scarping without consequential removal of sand to seaward of the foreshore. Neglecting the effects of non-wave-induced water level rises, (e.g. storm surges, extreme tides), cut of highly dissipative beaches primarily involves the second mode of cutting (Table 1). Pronounced setup on the landward margins of flat dissipative inshore profiles increases the effectiveness of return flows and may, under conditions of high energy or steep waves, allow the bores of broken waves to penetrate to the backshore or to the foredune base where scarping occurs as illustrated in Figure 5. This mechanism may operate to cause dune recession even where there is an abundance of inshore sediment and without necessarily resulting in a net loss of beach material. The setup normally oscillates at infragravity frequency with maximum bore penetration occurring at "surf-beat" highs.

Figure 4: Highly dissipative, barred surf zone near Goolwa, S.A. (surf zone is 500 metres wide).

Data from Goolwa (Jan-Feb 1980) and Seven Mile Beach (Feb.1979) emphasize the dominance of infragravity oscillations on the subaerial beach processes of dissipative systems. Figure 6 shows simultaneous water surface (η) time series from three different stations across the Goolwa surf zone. Progressive shoreward attenuation of oscillations at incident wave frequency and shoreward growth of infragravity oscillations at periods of 100-150 seconds are apparent. Power spectra of both η and shore normal current, u (Fig.7) from the inner surf zone are strongly dominated by infragravity peaks. Infragravity oscillations near the beach at Goolwa exceeded 1 metre in

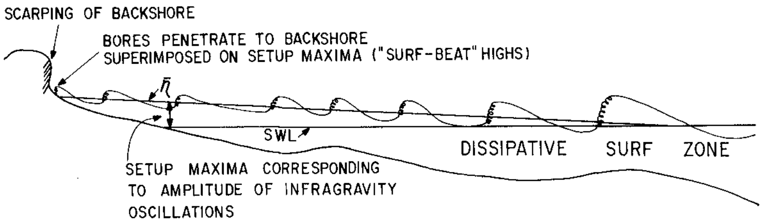

Figure 5: Cut of highly dissipative beaches: bores penetrate to foredune base on highs of infragravity oscillations.

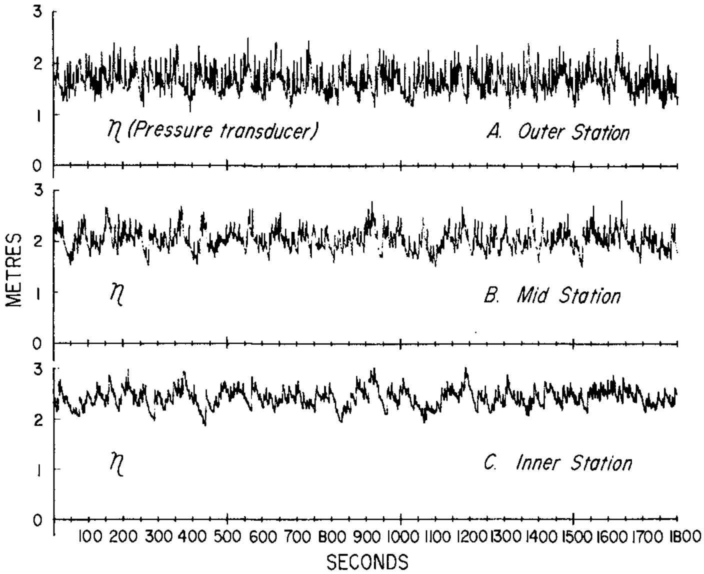

Figure 6: Simultaneous water surface (η) time series from Goolwa Surf Zone (1 Feb.1980) showing progressive shoreward attenuation of incident waves and growth of infragravity oscillation. Outer, mid, and inner stations were located respectively at 160m, 100m, and 60m seaward of the mid swash zone.

height at the time the data were obtained.

Seaward transport of sands within the surf zones of long straight dissipative beaches such as Goolwa Beach is the result of vertical segregation of shoreward versus seaward flows rather than rips. Figure 8 shows the cross-sectional current structure as observed at Goolwa under conditions of comparative beach stability. Strong shoreward flow near the surface is accompanied by weaker seaward flow near the bed. Spectra indicate the seaward flows to be dominated by infragravity pulsing. Although no storm data exist from such a high energy surf zone, it may be tentatively inferred that seaward-directed bottom flows intensify under storm conditions and move sand to the outer surf zone.

Cross spectra of and u and current statistics from multiple positions across the Goolwa and Seven Mile Beach surf zones demonstrate that the infragravity oscillations are standing in the shore-normal direction and may exist as longshore-progressive edge waves (Wright, in prep). The inferred antinodal regions normal to the shore approximately correspond to regions of sediment accumulation at bars. On long straight dissipative beaches, sediment eroded from the subaerial beach remains within the surf zone as multiple longshore bars from where it may be readily returned to the beach during periods of falling wave height. However when highly dissipative conditions and associated strong infragravity oscillations are superimposed during storms or periods of heavy swell, on crenulate coasts where short embayed beaches are bounded by headlands, erosive effects may be greatly enhanced. This is often the situation for many of the beaches near Sydney. Destructive effects and increased erosion hazards which are related to embayment geometry include: (1) low-frequency resonance at infragravity and seiche frequencies; and (2) giant, powerful storm rips which may transport sediment to over a kilometre offshore. The storm rips have feeder systems which may occupy the whole of an embayment (see Figure 8 of Wright et al., 1979b for an example). In many cases the rips appear to be closely coupled to low-frequency resonant phenomena and pulse strongly at periods of several minutes.

CUT OF INTERMEDIATE BEACHES

Time varying beaches, must in the process of shifting from one extreme state to the other, pass through the intermediate states shown in Figure 1. The period of time that the beach occupies any of these states may, in some cases, be very short as for example during a period of rapid erosion. However, in regions which experience highly variable wave climates like that of Eastern Australia the

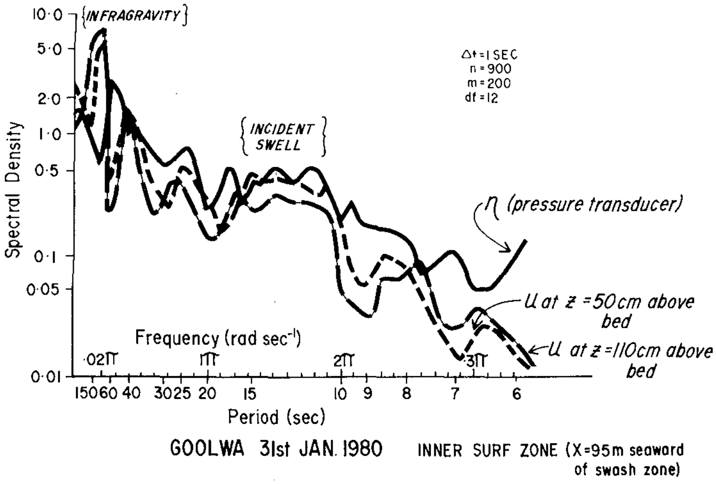

Figure 7: Power spectra of η and u from the inner surf zone at Goolwa (31 Jan.1980) showing strong dominance of infragravity oscillations.

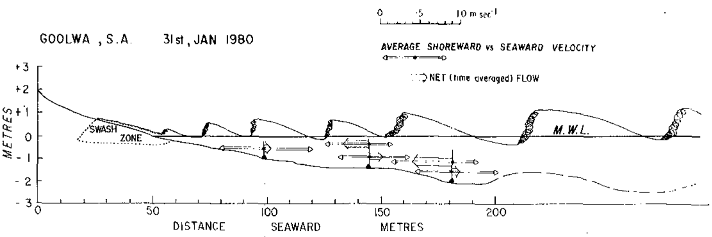

Figure 8: Cross-sectional current structure of the Goolwa surf zone (31 Jan.1980).

beach may continually oscillate around one or several intermediate states without reaching either extreme. In addition, some intermediate states may persist for several months or even year round on many of the compartmented beaches of New South Wales. Environmental conditions which favour intermediate modal states include moderate energy but temporally variable wave climates and medium to coarse sand.

Intermediate beach states include various types of bar-trough, crescentic bar, and rhythmic transverse-bar-rip topographies which allow part of the beach inshore system to be reflective while another part is dissipative (Wright et al., 1979a). For example steep reflective subaerial beaches can coexist with partially dissipative surf zones when deep pronounced troughs separate the beach from the dissipative parts of the surf zone or where the reflective beach sectors occur in rip embayments adjacent to dissipative transverse bars. Under these conditions the beach is affected by a combination of incident waves, subharmonic resonance, and infragravity oscillations, as well by resonance at intermediate frequencies determined in part by topographic dimensions (Wright, in prep). An example of current spectra from the inner surf zone of Type 3 intermediate topography (as described by Wright et al., 1979a) and exhibiting all of the frequencies just mentioned is shown in Figure 9.

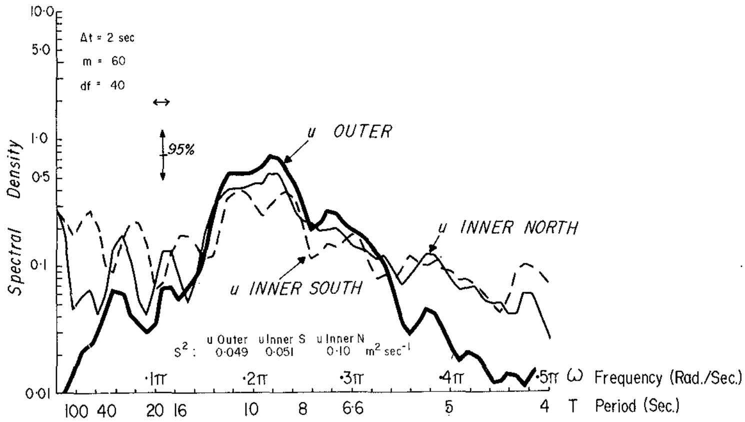

Figure 9: Power spectra of u from intermediate crescentic-bar-trough topography on North Moruya Beach (13 Dec.1977).

Intermediate states permit both Mode 1 and Mode 2 cut to operate together when seas rise. In addition, it is on the intermediate states that different scales of rip circulation are best developed so that Mode 3 cut also plays an important and often major role. Mode 3 cut is associated with rip circulations which are forced by topographic irregularities (e.g., transverse bars and alternating embayments), particularly irregularities which are persistent in their location. Localized but often severe erosion may occur in the embayments of rips, even when the coast regionally is experiencing accretion, by means of current scour at the base of the beach face. Paradoxically, this form of erosion may be intensified by abnormally rapid accretion in immediately adjacent zones or by the nearby occurrence of arrested shore-line protrusions such as tidal inlets or man-made structures, which produce steep alongshore gradients in radiation stress and setup. Despite its spatial limitations, this mode of erosion may cause chronic local shoreline recession, often endangering beach front properties. Figure 10 shows an example of a large arrested rip system on Wamberal Beach north of Sydney which caused the destruction of three beach-front properties at a time when the flanking shoals were rapidly accreting.

A large-scale analogue to Mode 3 cut occurs adjacent to river mouth bar deposits and deltaic lobes influenced by moderate to high energy waves. This type of erosion is related to large-scale rips which drain water trapped by high dissipative wave breaking over the seaward-protruding river-mouth bar or deltaic bulge deposits. Large erosional bays result along margins of the regions of high deposition rates. This form of erosion is most acute on the downdrift margins of the depositional bulge but also occurs on the updrift margins. An example from the mouth of the Shoalhaven River south of Sydney is shown in Figure 11. The process of delta-margin erosion is also discussed by Wright et al., 1980.

DISCUSSION AND CONCLUSIONS

This paper has emphasized the dependence of beach cut on morphodynamic state. The probability of some form of cut occurring, the possible severity of cut and the mode of cut all vary with morphologic state on the one hand and breaker conditions and sediment size on the other. Quite obviously, the threat to beach front properties depends as much on the absolute width of the subaerial beach as it does on cut probability. However for any given beach width, the relative erosion "hazard" of a beach sector may be readily assessed at a first order with reference to beach state, degree of exposure, and forecast wave

Figure 10:

Topographically arrested rip on Wamberal Beach (north of Sydney) which caused chronic shoreline recession and resulted in the destruction of beach front homes.

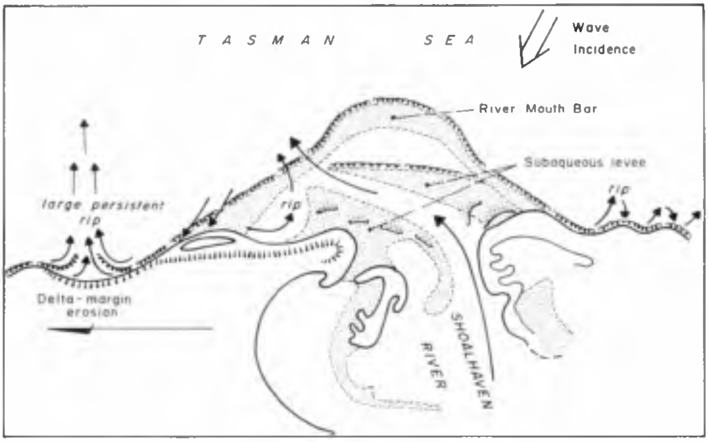

Figure 11: Delta-margin erosion adjacent to river-mouth bar deposits, mouth of Shoalhaven River (south of Sydney).

conditions. Since the physical processes responsible for cut are different, different beach protection strategies may be required for different morphodynamic states. For purposes of long-term advance planning, it is the modal beach states and/or normal range of states that are important. These may be recognized from sets of long-term ground or remotely-sensed observations.

On many New South Wales beaches, particularly those along the crenulate coast in the vicinity of Sydney, modal beach state varies appreciably with degree of exposure to the dominant southeasterly swell and storm waves. Spiral or zeta curved embayments typically are protected and experience low refraction coefficients at their southern ends but are fully exposed at their northern ends. Reflective beaches are the modal state in the southern sectors whereas the accumulation of sands within the surf zone combined with high exposure tends to maintain more dissipative conditions at the northern ends. Intermediate states are most common in the middle sectors. This pattern of longshore variation in beach state together with the associated variations in likely mode of beach cut is illustrated in Figure 12. Typically it is the middle (intermediate) sections of these beaches which are most susceptible to cut and are most mobile. In a more general sense, Table 2 summarizes the relationships between beach state, beach mobility and environmental conditions.

Table 2: Modal Beach State and Beach Mobility in Relation to Environmental Conditions.

'MODAL' BEACH STATE	RELATIVE AMPLITUDE OF CHANGES IN SHORELINE POSITION	ENVIRONMENTAL CONDITIONS
REFLECTIVE	*LOW*	*Low-steepness waves or strongly embayed compartments; coarse or high-density (e.g. volcanic 'black' sands) material*
DISSIPATIVE	*LOW TO MODERATE*	*Persistent high energy waves or Abundant fine sands in inshore zone (e.g. deltaic coasts)*
INTERMEDIATE-RHYTHMIC	*HIGH*	*Highly variable wave climate; medium sands; best developed where there is also a significant fraction of shell fragments and a meagre sediment supply.*

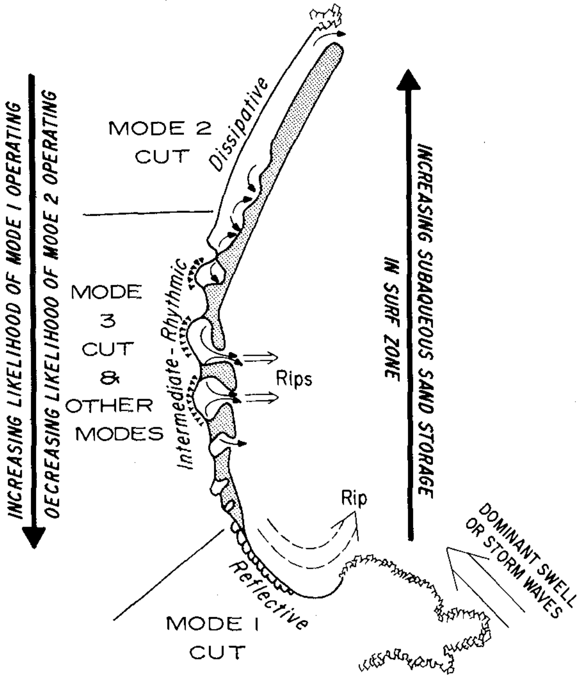

Figure 12: Longshore variation in modal beach state and associated modes of beach cut in a typical New South Wales spiral embayment.

ACKNOWLEDGEMENTS

This study has been supported by the Australian Research Grants Committee and by the U.S. Office of Naval Research, Coastal Sciences Program, Task NR 388-157, Grant N-00014-80-G-0001. I am grateful for assistance provided throughout the study by M.P. Bradshaw, F. Coffey, P.J. Cowell, M. Green, and A.D. Short. Figures were prepared by J. Roberts and M. Rigney.

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