CHAPTER 68

MORPHODYNAMIC VARIABILITY OF HIGH-ENERGY BEACHES

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Abstract

Field observations of beach and inshore morphology and of surf and inshore current spectra using an array of pressure transducers and low-inertia bidirectional flow meters interfaced with an in-field mini-computer/logging system have been replicated on several beaches in southeastern Australia under a range of energy conditions. Two broad extremes of beach conditions are distinguished spatially and temporally: (1) reflective systems in which much of the incident wave energy is reflected from the beach face; and (2) dissipative systems with wide surf zones and high turbulent viscosity. Reflectivity increases as the ratio of wave steepness to beach (or bed) steepness decreases. Compared to steep, unbarred reflective beaches which are common in deeply indented or partially protected compartments, the topography of exposed dissipative systems is more complex and varied: six time-and-environment-dependent morphologic types with different bar patterns and bar-beach relationships are recognized. The greatest total dissipation prevails in regions of most abundant inshore sediments or during and immediately after severe storms. Between the reflective and dissipative extremes there is a hierarchy of observed resonant frequencies with the highest frequency resonance occurring in the most reflective cases. Results indicate that near the beach face, motions associated with resonance at periods greater than incident wave periods exhibit strong net seaward resultants and are probably important sources of beach erosion. Reflective beaches are sensitive to resonant excitations over a wider range of frequencies and under lower energy conditions than are dissipative beaches. Hence, although reflective beaches represent the accretive end point of a "beach cycle" they are also more delicately poised with a higher potential for erosion.

Introduction

Beach and inshore systems on the New South Wales coast of south-eastern Australia (*Fig. 1*) exhibit pronounced morphologic and dynamic variability with respect to both time and local environment (Wright et al., in press). The coast is characterised regionally by a steep marine-dominated inner shelf. Rocky headlands separate embayed beaches which occupy pronounced coastal compartments, of widely varying dimensions. Inshore processes are dominated by a relatively high energy wave regime with a highly variable wind-wave climate superimposed on persistent long southerly and southeasterly swell. Significant wave heights of 1.5m, 2.5m and 4m are respectively exceeded for 50%, 10% and 1% of the time; storm waves exceed heights of 10m (Lawson and Abernethy, 1975). Semi-diurnal spring tide range is 1.6m.

Field observations of beach and inshore morphology, surf and inshore current spectra, and inshore circulation patterns have been replicated in several constrasting beach environments for a range of energy conditions. An array of pressure transducers and low-inertia bidirectional flow meters interfaced with an in-field mini-computer/data acquisition system was used to obtain wave and current data. The system permits simultaneous logging and analysis of time series from 16 channels. (See Bradshaw et al., 1978 for detailed description of field instrumentation)

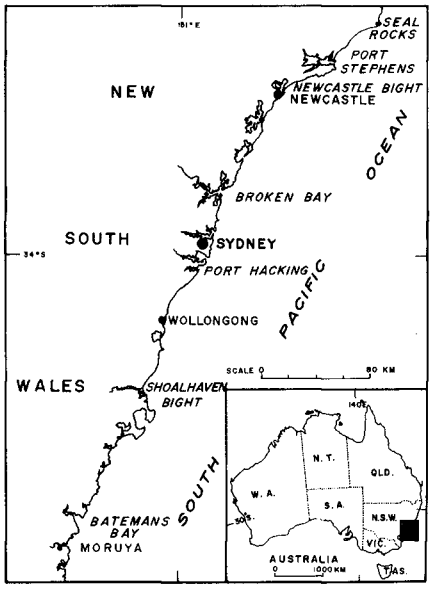

Figure 1: Location Map of study area and major beach sites

Variability of Beach Conditions

Two broad extremes of beach conditions are distinguished spatially and temporally: (1) *reflective systems* in which much of the incident wave energy is reflected from the beach face; and (2) *dissipative systems* with wide surf zones and high turbulent viscosity. The degree of reflectivity depends in a gross sense on the surf scaling parameter as defined by Guza and Bowen (1975 by

$$\varepsilon = a\omega^2 / g \tan^2 \beta \qquad (1)$$

where a is breaker amplitude, ω is radial frequency ($2\pi/T$ where T is period) of the waves, g is the acceleration of gravity and β is beach or inshore slope. Highly reflective conditions are associated with ε values less than $\sim$ 2.0 whereas in the case of fully dissipative systems ε normally exceeds 30.0 in the vicinity of the breakers. Reflective conditions persist for most of the year in deeply indented compartments, on partially protected estuarine beaches, and on beaches composed of coarse material. Dissipative systems prevail in most of the exposed, open coast situations except after prolonged periods of accretion and low wave energy (Wright et al., in press).

Reflective Beaches

Reflective beaches are characterised by the profile configuration shown in *Figure 2*. Distinguishing features include: (1) a linear, low gradient nearshore (i.e., seaward of break) profile composed of fine sand; (2) a pronounced step composed of the coarsest available material; (3) a steep, linear beach face surmounted by a high berm; (4) well-developed beach cusps; and (5) surging breakers with high runup and minimum setup. The step below the beach face is situated beneath the shore break which is also the position of collision between backwash and incident waves. The depth of the step base increases with increasing wave energy. The reflective condition is normallymaintained throughout the tide cycle. Features such as ridge and runneltopography, swash bars, and inshore troughs are consistently absent from such reflective systems. Large-scale inshore (subaqueous) rhythmic topographies are completely absent. Similarly, inshore circulation cells and rip currents are rarely present except during storms. The most conspicuous three-dimensional features are well-developed beach cusps on the beach face and berm. An oblique view of Bracken(McKenzies) Beach, a typical reflective beach on which many of our experiments were conducted, is shown in *Figure 3*.

Wave height and current spectra (*Figure 4*) from reflective beaches consistently have their dominant peaks at incident wave (T) and subharmonic (2T) periods and cross spectra indicate the existence of low-mode edge waves at those periods. Edge wave lengths are consistently well correlated with cusp spacing (Wright et al., 1977, in press). Infragravity peaks are not important. Under low energy conditions subharmonicpeaks are low relative to incident wave peaks; however,

increasing breaker height tends to be accompanied by increasing subharmonic energy. Growth of subharmonic resonance is accompanied by an increase in the strength of seaward flows which pulse at the subharmonic period. Subharmonic seaward pulsing thus appears to be a major mode of erosion of reflective beaches, at least, in the early erosional stages.

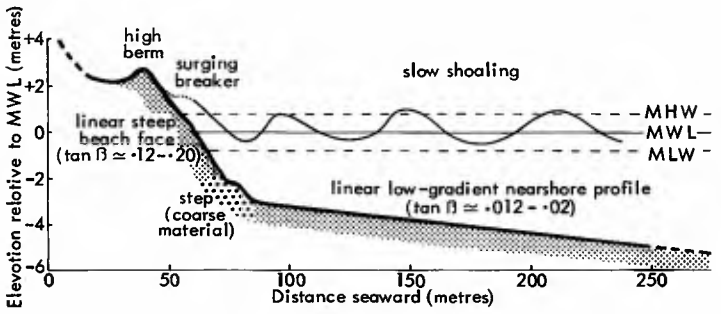

Figure 2 : Typical cross section of a reflective beach

Figure 3 : Oblique Photograph of Bracken (McKenzies) Beach: a predominantly Reflective Beach

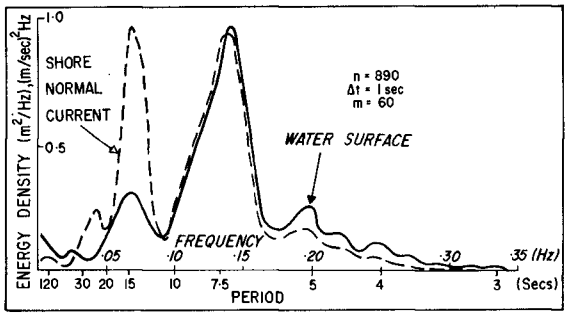

Figure 4: Typical Power Spectra of wave height and shore normal current time series from a reflective beach (Bracken Beach Dec. 1977; sensors located 3 metres seaward of step)

Dissipative Beach Systems

Dissipative systems are fronted by concave upward nearshore (seaward of break) profiles and wide flat inshore profiles (*Figure 5*). Waves break 75 to 300+ metres seaward of the beach and dissipate much of their energy before reaching the beach, creating significant radiation stress gradients and setup. Topography is much more complex and varied than in the case of reflective beaches; one or more bars, three-dimensional inshore topography, and different scales of rip cells are frequently present. It is common for dissipative systems to become segregated into subregions of contrasting turbulent viscosity such that a highly dissipative inshore zone may front a moderately reflective beach face. It is therefore necessary to separate the surf scaling parameter into an inshore value, ε_s and a beach face value ε_b. Wright et al. (in press) have classified dissipative beaches into the six basic types shown in *Figure 6*. Each type is dominated by a distinctive combination of surf-zone processes and by different scales and frequencies of resonant phenomena.

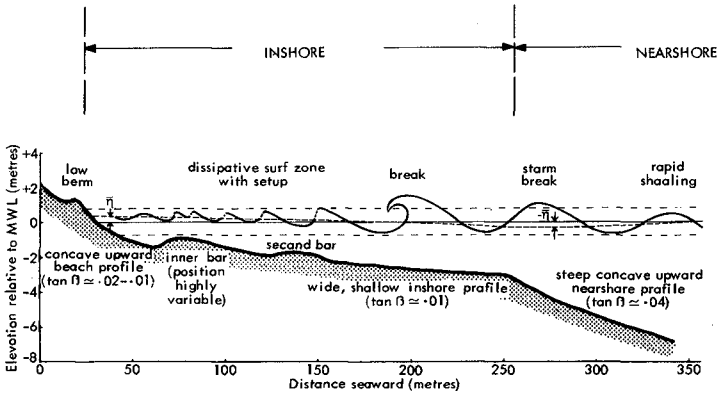

Figure 5 : Typical cross section of a dissipative beach

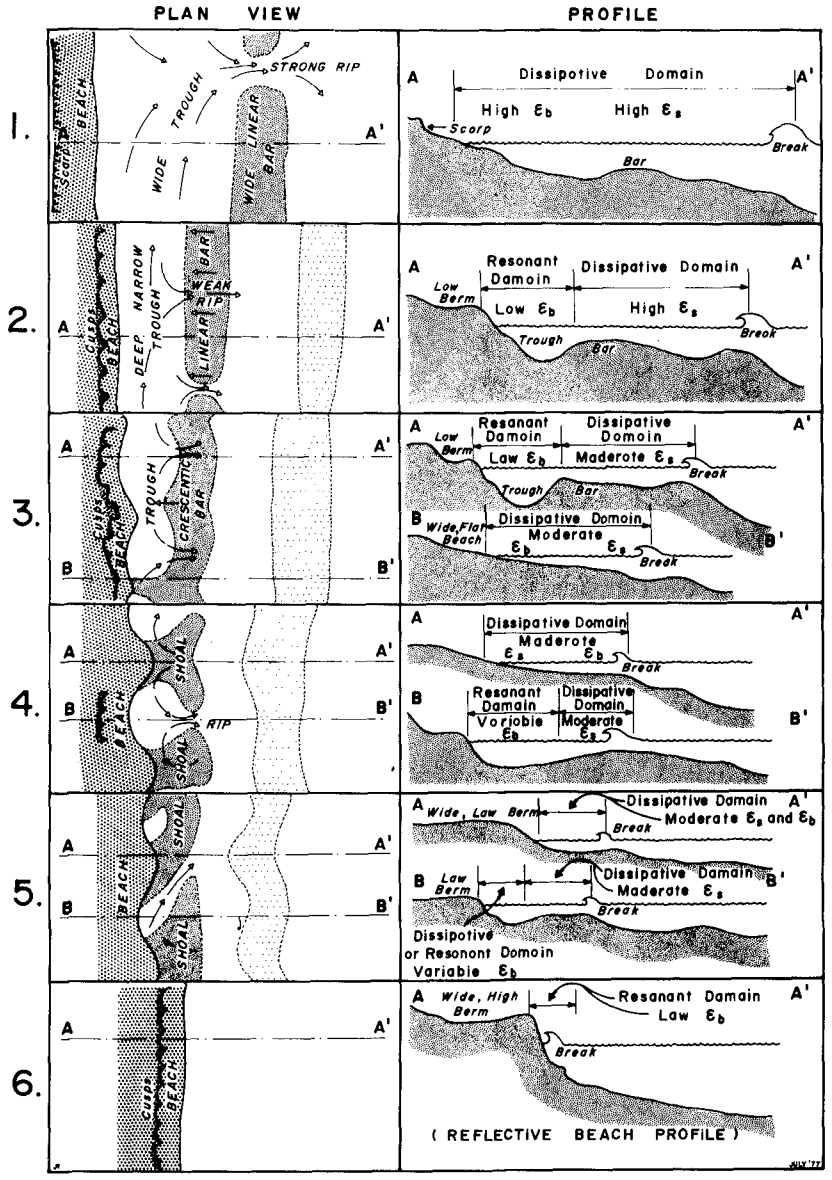

Figure 6 : Six major types of high-energy dissipative beach/inshore systems

The greatest total dissipation is associated with *Type 1 (Figure 6)* which prevails in the regions of most abundant inshore sediments or during and immediately after severe storms. *Type 1* is dynamically similar to beaches in deltaic regions where abundant inshore sediments sustain very flat profiles. Where it develops on high-energy beaches away from major depositional regions, *Type 1* is a manifestation of sub-aerial beach erosion under extreme energy conditions. At least one well developed bar lies 100-200 metres seaward of a flattened beach face. Additional bars may occur farther seaward. Both the inshore zone and the beach face are highly dissipative. Setup is highest and runup is lowest with *Type 1* and the dominant energy near the beach is at surf beat periods (80-150 sec.). Along longer and straighter beaches multiple longshore bars may remain unbroken by rips. Multiple bars are particularly prominent at the northern ends of large depositional bights (e.g., *Figure 7*) where accumulation of abundant sediments creates wide, flat nearshore/inshore profiles. As in deltaic settings, this situation can result in the maintenance of highly dissipative conditions even under moderately low energy conditions. Under these conditions the parallel bar patterns conform well with patterns predicted from the theory of long-crested leaky-mode infragravity standing waves (Suhayda, 1974; Short, 1975). However, on the more highly compartmented beaches the development of *Type 1* topography is often accompanied by one or two rips which extend up to 1 to 2 km seaward (*Figure 8*). These large, powerful rips commonly exhibit a very low frequency pulsing at periods of 5 to 10 minutes and are very destructive in their effects. Observations of storm-rip pulsing on Palm Beach (*Figure 8*; Cowell, 1975) and on Cronulla Beach (Lees, 1977) show remarkable correspondence with the natural frequency of the compartments.

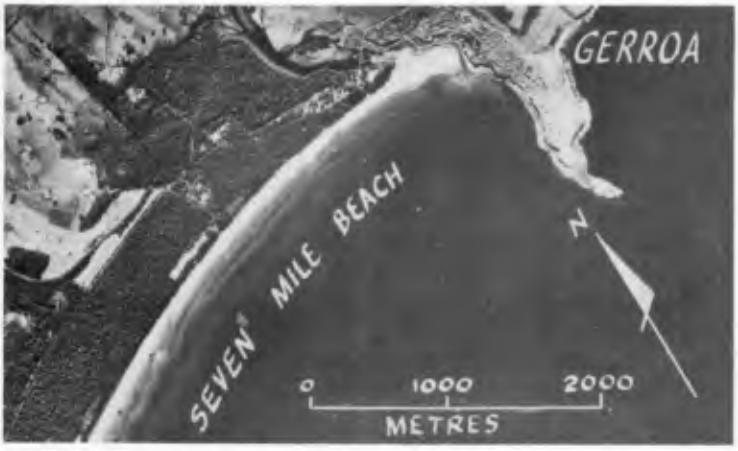

Figure 7: Multiple Parallel bars related to *Type 1* topography (Shoalhaven Bight, N.S.W.)

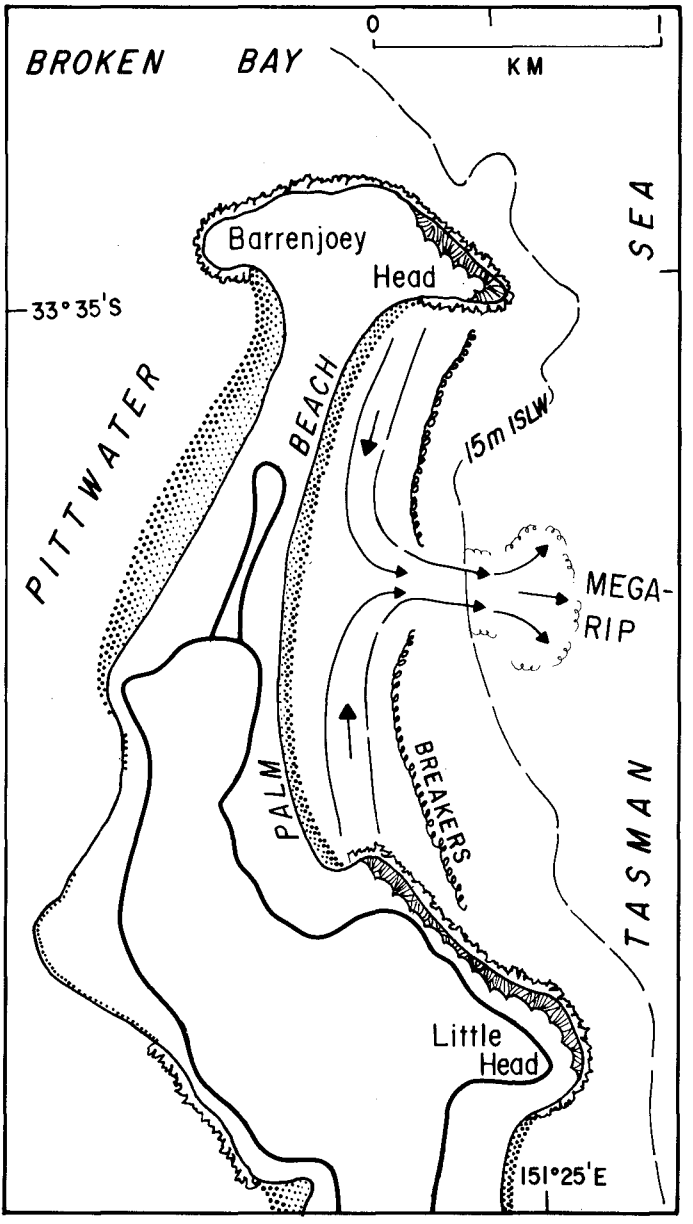

Figure 8 : Large scale "megarip" circulation system related to *Type 1* conditions on a highly compartmented beach (Palm Beach, N.S.W.)

Type 2 develops as the bar migrates shoreward under the influence of the progressive shorter period (incident wave period, T and its harmonic T/2) components of surf motion when the wave height diminishes to more moderate energy levels. As the bar migrates shoreward the beach face steepens and a deep trough develops within which the partially dissipated waves reform (*Figure 9*). Although the outer surf zone remains dissipative, low turbulent viscosity prevails within the trough and low ε_b values characterize the beach face. Synchronous and subharmonic resonance occurs near the beach face, and, as with reflective beaches, low-mode edge waves form beach cusps. A conspicuous feature of *Type 2* and *3* is the occurrence of pronounced resonant spectral peaks at 4T (40-50 sec.) within the trough and on the bar. Lower frequency surf beat peaks also remain present but are secondary. An example of power spectra of surf zone surface oscillations over the bar and within the trough of *Type 2* is shown in *Figure 10*. The development of the narrow-band peak at 4T within the trough is readily apparent. Rips which pulse at surf-beat periods (100-150 secs.) commonly cross or cut the bar at widely spaced intervals. *Type 2* can persist for several weeks under swell-dominated conditions.

Type 3 is distinguished by a highly regular and rhythmic crescentic bar (*Figure 11*). Shoreline undulations and well-developed circulation cells with evenly spaced rips are also common. Rips and crescentic features have spacings of 100-200 metres. Edge waves with periods corresponding to the observed resonant spectral peaks at 4T (40-50 secs) are probably responsible for the crescentic forms and periodic circulation cells. Rip-current spectra exhibit dominant peaks at 4T indicating pulsing at that period. As with *Type 2*, the beach face remains relatively reflective, but with the lowest ε_b values and highest runup prevailing behind crescentic embayments, where low mode synchronous and subharmonic edge waves commonly exist near the beach face.

Well-developed rhythmic topography with alternating transverse bars and pronounced embayments characterize *Type 4* (*Figure 12*). Transverse bars are frequently anvil-shaped but cuspate bars similar to those described by Sonu(1973) may also occur. The topography may also be skewed alongshore under conditions of oblique breaker angles. Narrow, well-defined rips occupy embayments while net shoreward transport occurs over shoals as observed by Sonu(1972, 1973). Where shoals weld to the beach, both ε_s and ε_b remain high and runup is low; however, the beach face behind embayments remains steep, ε_b is normally less than 2, and runup is high. A step is usually present at the base of the beach face. In an accretionary sequence, the spacings of rips and transverse bars appear to be largely inherited from *Type 3*. However, the primary rip circulation cells associated with *Type 4* are probably topographically induced.

Spectra of shore-normal and shore-parallel current motion and water surface oscillations as observed in the presence of *Type 4* topography show dominant, broad surf beat (80-150 secs) peaks near the beach face where the transverse bar attaches to the shore. Rips pulse at corresponding periods. In contrast to transverse bar spectra, current and surface oscillation spectra from the step region behind rip bays also show strong peaks at T and 2T.

Figure 9 : Shore-parallel bar and deep pronounced trough of *Type 2* topography (Moruya Beach, N.S.W.). Note wave breaking and partial dissipation over the bar and reduced turbulence in the trough.

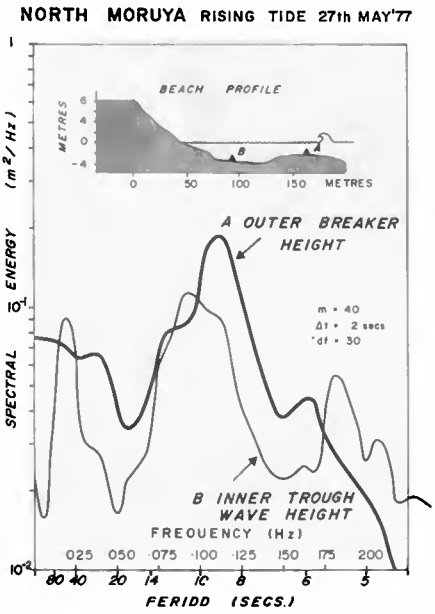

Figure 10 :

Power spectra of water-surface oscillation over the bar and within the trough of *Type 2* topography (Moruya Beach, N.S.W.)

Figure 11 :

Rhythmic crescentic bar patterns associated with *Type 3* topography (Erunderee embayment near Seal Rocks, N.S.W.)

Figure 12 : Rhythmic transverse bars and rip embayments of *Type 4* topography (Cronulla Beach, N.S.W.)

Extensive inshore shoals at the base of a moderately steep beach face distinguish *Type 5* (*Figure 13*). The shoals develop following long periods of low energy or in relatively protected regions with abundant inshore sediment. The shoals are crossed at irregularly-spaced intervals by narrow rip channels which atrophy with continued accretion. With *Type 5*, ε_b varies appreciably with tide. At low tide dissipation is virtually complete before the waves reach the beach; runup is very low and motion near the beach is dominated by low-energy infragravity oscillations. At high tide, however, runup is high and synchronous and subharmonic resonance occurs. *Type 5* can persist for prolonged periods of 2 to 3 months under sea-breeze dominated summer conditions provided no high energy events occur.

Figure 13 : Intertidal shoals and atrophied rip channels associated with *Type 5* topography

Type 6 morphology (*Figure 14*) represents the fully accreted beach state and occurs after prolonged periods of low swell. It is generally rather rare on exposed, otherwise dissipative surf beaches. *Type 6* is a reflective beach with a steep linear beach face and a very high berm which remains continuous for long distances alongshore; rips are always absent. Wave and current spectra are also similar to those described for reflective beaches.

Figure 14 : Steep Reflective beach and high berm associated with *Type 6* topography (near Port Stephens, N.S.W.)

Discussion

The spectrum of motions in any given surf zone is made up of numerous progressive (dissipative) and standing (reflective) components (Huntley et al., 1977). On a steep reflective beach oscillations at incident wave period are normally standing near the beach; however, with increasing ε and increasing surf zone viscosity, high frequency reflection is suppressed and the periods which can be standing increase through a progression of subharmonics (jT; where j = 2 or 4) to surf-beat (T_b = 80-150 secs) to a very low frequency seiching at periods (T = 5-10 min) near the natural compartment period. The standing oscillations can exist either as "leaky" modes in which the reflected energy is re-radiated back to sea (e.g, Suhayda, 1974), or as resonant trapped edge waves; the latter appear to be common except under the most dissipative extremes (*Type 1*) on long straight beaches. Increasing resonant period is accompanied by increasing scale (i.e., spacing between rips and associated rhythmic morphology) and intensity (i.e., rip velocity) of circulations. The progression of resonant modes through a series of discrete frequencies implies firstly that beaches do not vary between reflective and dissipative extremes on a continuum but probably shift abruptly to different states. Secondly, a hierarchy of "nested" circulation and morphologic elements can occur.

Segregation of shore-normal current spectra into shoreward and seaward components (e.g., Wright et al., In press) indicates that on any given beach or inshore slope, significant shoreward movement near the bed is dominated by progressive dissipative bores with periods equal

to those of the incident waves (T) and their harmonics (T/2). Near-bed current motions associated with resonant oscillations at periods greater than incident wave period (i.e., 2T, 4T, and surf beat) exhibit strong net seaward-directed resultants, suggesting that low frequency resonance plays a major role in causing seaward sand transport. Where synchronous resonance at the dominant incident wave period, T, prevails (e.g., on reflective beaches), the shoreward and seaward velocities are approximately balanced for oscillations at that period. This balance tends to prevail on steep reflective beaches and in the immediate vicinity of the beach face of some dissipative beach types (*Types 2, 3* and *6*, and in the rip embayments of *Type 4*) where incident waves are commonly standing. However, cross spectra reveal that away from the beach face over flat, dissipative inshore profiles the higher frequencies (T and T/2) are progressive and dissipative. The shoreward decay of these progressive components is accompanied by a shoreward increase in resonant energy at lower frequencies. The shore-normal direction (i.e. onshore or offshore) of net sediment transport at any given inshore position depends on the energy of the high frequency progressive components relative to the energy of lower frequency resonant components.

On very flat, highly dissipative, profiles resonance at intermediate frequencies (2T, 4T) is suppressed or weak whereas possible resonance at very low frequencies (surf beat or compartment seiching periods) requires high energy dissipation in order to become dominant over the accretive progressive bores. Hence, although the fully dissipative system represents the end point of an erosional sequence, its large inshore sediment storage and flat gradient give it the greatest potential for experiencing future accretion. In contrast, highly reflective beaches (and *Type 6* profiles: the accretive and point) are, owing to their steep gradients and subaqueous sediment deficit, sensitive to resonant excitations over a wide range of frequencies and may experience erosion under moderate swell conditions as soon as resonant energy at 2T (first subharmonic) exceeds incident wave energy near the beach. The reflective beach is thus delicately poised with a high erosion potential.

At any specific beach locality the morphodynamic state can vary from *Type 1* to *Type 6* with time and depending on antecedent energy conditions. The most exposed localities show the greatest variability between states. The persistence of a given type also varies spatially with local environment. *Types 1* and *2*, often with multiple bars, are common at the northern ends of large depositional bights, particularly in cases where there is an abundance of sediment. *Types 2, 3* and *4* are frequently encountered in fully exposed middle sections of coastal compartments. *Type 5* is most likely to be persistent on stretches of beach less exposed to high energy swell, but exposed to shorter wind-generated waves. *Type 6* is often present in the partially protected southern ends of compartments in the lee of headlands; it is particularly prominent in the southern arcs of log-spiral or "zeta-curved" compartments. Significantly, although these last environments experience low energy for most of the time, they are chronically susceptible to appreciable erosion under heavy swell conditions.

Acknowledgements

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References

Bradshaw, M.P., J. Chappell, R.S. Hales and L.D. Wright, 1978 "Field Monitoring and real-time analysis for surf and inshore current behavior" Proc. 4th Aust. Coastal and Ocean Engineering Conference (Adelaide) 171-175.

Cowell, P.J. 1975 Morphodynamic Aspects of the Interactions Between Incoming waves and Bed Topography at Palm Beach, N.S.W. Unpublished B.A. Hons. Thesis, Dept. of Geography, University of Sydney, 179 pp.

Guza, R.T. and A.J. Bowen, 1975 "The resonant instabilities of long waves obliquely incident on a beach" J. Geophys. Res. 80: 4529-4534.

Huntley, D.A., R.T. Guza, and A.J. Bowen 1977 "A universal form for shoreline runup spectra?" J. Geophys. Res. 82: 2577-2581.

Lawson, N.V. and C.L. Abernethy, 1975 "Long term wave statistics off Botany Bay" Proc. 2nd Aust. Conf. on Coastal and Ocean Engineering (Gold Coast, Qld) 167-176.

Lees, B.G. 1977 The Effects of Compartmentalization on Beach Processes and Forms: Cronulla, N.S.W. Unpublished B.A. Hons. thesis, Dept. of Geography, University of Sydney.

Short, A.D. 1975 "Multiple Offshore bars and standing waves" Jour. Geophys. Res. 80: 3838-3840.

Sonu, C.J. 1972 "Field observations of nearsbore circulation and meandering currents" J. Geophys. Res. 72: 3232-3247.

Sonu, C.J. 1973 "Three dimensional beach changes" J. Geol. 81: 42-64.

Suhayda, J.N. 1974 "Standing waves on beaches" J. Geophys. Res. 79: 3065-3071.

Wright, L.D., B.G. Thom, P. Cowell, M. Bradshaw and J. Chappell 1977 "Field observations of resonant surf and current spectra on a reflective beach and relationships to cusps" SEARCH 8: 321-322.

Wright, L.D., J. Chappell, B.G. Thom, M.P. Bradshaw and P. Cowell In press "Morphodynamics of reflective and dissipative beach and inshore systems, Southeastern Australia" Marine Geol.