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A "blind-folded" test of equilibrium beach profile concepts with New Zealand data

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ABSTRACT

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Methodology for calculating equilibrium beach profiles for uniform sand size characteristics is extended to the case of an arbitrary distribution of sediment characteristics across the profile. The application of this method and comparison with actual profiles is posed as a means of interpreting whether the profile contains a deficit or excess of sediment and thus whether long-term shoreline recession or advancement can be anticipated. Various types of profile disequilibrium are reviewed and the significance discussed. The methodology is applied using measured profiles, sediment sizes and beach face slopes for ten sites on the Northern Island of New Zealand. One profile was documented in this study, whereas the data for the other nine were obtained from published sources. The number of sediment samples available for each profile varied from three to twelve. The agreement between the actual and calculated profiles differs considerably for the ten sites. The degree of disequilibrium is quantified by calculating the shoreline adjustment, Δy, required for the actual profile to equilibrate for depths less than 7 m, which represents the near-maximum depth available on all profiles. These shoreline adjustments ranged from -105 m (recession) to $+159$ m (advancement) with four of the ten sites having positive values. Three of the sites with negative shoreline adjustments have been, or are presently, sites of substantial sand extraction from the beach or in the nearshore waters. However, the differences between the actual and equilibrium profiles are not consistent with anticipated profile forms and/or volumes and it is thus concluded that sand mining is not responsible for most of the observed deficits. At this stage, it is not possible to state with confidence whether differences between actual and (calculated) equilibrium profiles are due to true disequilibriums or to limitations in the equilibrium beach profile methodology. Studies of the type reported here when applied to many different areas will advance the methodology and contribute to the confidence in the resulting interpretations.

Introduction

Beaches are acted on and the product of a complex system of forces and processes, including sediment supply and hydrodynamics. The sediment supply can include marine and terrigeneous components, some of which may be biogenic or hydrogenic in origin. The hydrodynamics includes cross-shore and longshore flows resulting from normal and storm wave activity, short-term pulses of storm-induced increased sea-level and secular trends due to relative sea-level changes and local ground movement. If the forcing system could be maintained in steady state, it seems reasonable that, given sufficient time, the beach system would tend towards a 3-D equilibrium.

Various portions of the beach profile respond with different time scales; in general, the shallow portions of the profile respond much more rapidly than those in deeper water. This concept is illustrated in Fig. 1; however, because the time scales depend on wave climate and other factors, actual profile response times will vary from location to location.

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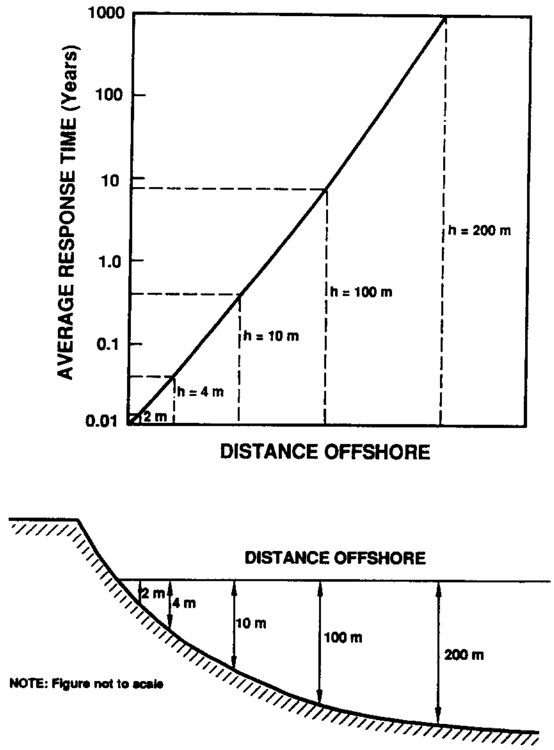


Fig. 1. Concept of increasing response times for greater water depths.

Considerable advances have been made in the understanding of beach systems over the past several decades. These advances have been due largely to improvements in the theory of breaking and broken waves with the attendant transfer of forces as well as to the clarifying results of several major field experiments (Nearshore Sediment Transport Study, Seymour, 1987; The Canadian Coastal Sediment Study, Willis, 1987; The Nearshore Environment Research Center Project, Horikawa and Hattori, 1987; DUCK '85, Mason et al., 1987). As an example, the significance of infragravity (long) waves and undertow to beach profile dynamics has been identified. Additionally, through careful measurements and by designing focussed experiments, laboratory studies have contributed to progress in understanding the complex mechanics and responses (e.g., Dette and Uliczka, 1987; Visser, 1986).

Notwithstanding the recent research programs and resulting substantial advances, the problem of understanding beach systems and predicting their response to force changes must still be regarded as rudimentary—in some cases even at the first order. For example, at most locations, there is not even an effective documentation of the long-term *trend* of shoreline change, which may be "masked" by seasonal shoreline variations that can be up to several hundred times greater than the annual trend rate. Nor do we have the capability to predict the seasonal shoreline fluctuations based on associated variations in tides, waves, winds and ground water-level fluctuations.

A more complete understanding of equilibrium beach profiles, the causative forces and the associated mechanisms would enhance the confidence in predicting response to future increases in sea level and would improve the capability to interpret profiles which are out of equilibrium to assess the dominant processes and the associated time scales for equilibrium. As each profile is the product of and contains information of all past and present forces which have acted to shape that profile, a wealth of information is contained within its form and sediment texture.

A significant utility of a capability to predict equilibrium beach profiles (EBP) would be to provide a consistent framework against which a range of profiles can be compared, possibly to test one or more hypotheses. Systematic differences between actual and predicted equilibrium profiles either establish deficiencies in the present EBP understanding, or identify profiles which are out of equilibrium. The present situation, as outlined above, is that the existing methodology for EBP is not fully substantiated so that any differences need to be considered carefully as to whether they are indicative of limitations of the methodology or differences due to the existing profile being out of equilibrium for one or more reasons.

This paper provides a "blind-folded" test of a simple equilibrium beach profile methodology using a newly-developed data set from the North Island of New Zealand. Additionally, approaches to interpreting profiles out of equilibrium are explored. The term "blind-folded" implies that the equilibrium beach profiles are not based on fitting to the existing profile (apart from the beach face slope), but rather are based on methodology to be described.

Methodology

The equilibrium beach profile model first presented by Bruun (1954) and documented by Dean (1977, 1991), is perhaps the most widely used today (Kriebel et al., 1991). It has been employed, in various forms and applications and with varying results, in recent work by Boon and Green (1988), Seymour and Castel (1988), Stockberger and Wood (1990) and Moutzouris (1991) amongst others. As will be evident, this model does not account explicitly for the detailed hydrodynamics of the nearshore zone.

This simple form for the equilibrium beach profile expresses the water depth, h, at a distance, y, from the shoreline in the power law form:

$$h(y)=Ay^{2/3} \tag{1}$$

in which A is a sediment size dependent scale parameter determined by Moore (1982) as shown by the solid line in Fig. 2. Later, Dean (1987) transformed the A vs. D relationship to the A vs. w (fall velocity) relationship, presented as the dashed line in Fig. 2 which is quite linear on the log–log plot and well-represented by the simple relationship:

$$A=0.067w^{0.44} \tag{2}$$

in which w is in units of ccentimeters per second and A is in meters$^{1/3}$.

Dean (1977) has shown that if the wave height, H, inside the surf zone is considered as proportional to the water depth, h, i.e.:

$$H=\kappa h \tag{3}$$

then Eq. 1 is consistent with uniform wave energy dissipation per unit water volume. Although κ in Eq. 3 is usually taken as 0.8 (McCowan, 1891), this relationship is an idealization of a complex process in which κ varies with beach slope and breaker type and for most natural slopes, κ is considerably less than 0.8. However, the *value* of κ is not critical to the present methodology nor to the argument of uniform wave energy dissipation per unit water volume. The interpretation of Eq. 1 is that, depending on its stability characteristics, a sediment particle can withstand a certain level of wave energy dissipation which is manifested by the transformation of organized wave energy into highly chaotic turbulent motions which tend to destabilize and mobilize the sediment particles.

One short-coming of Eq. 1 is that it predicts a vertical slope at the shoreline, $y=0$. In some respects, this is not surprising since the destabilizing effects of gravity have not been included. Nevertheless, Larson (1988) and Larson and Kraus (1989) have shown that if the more realistic wave breaking model of Dally et al. (1985) is used instead of Eq. 3 and the requirement of uniform wave energy dissipation per unit volume specified,

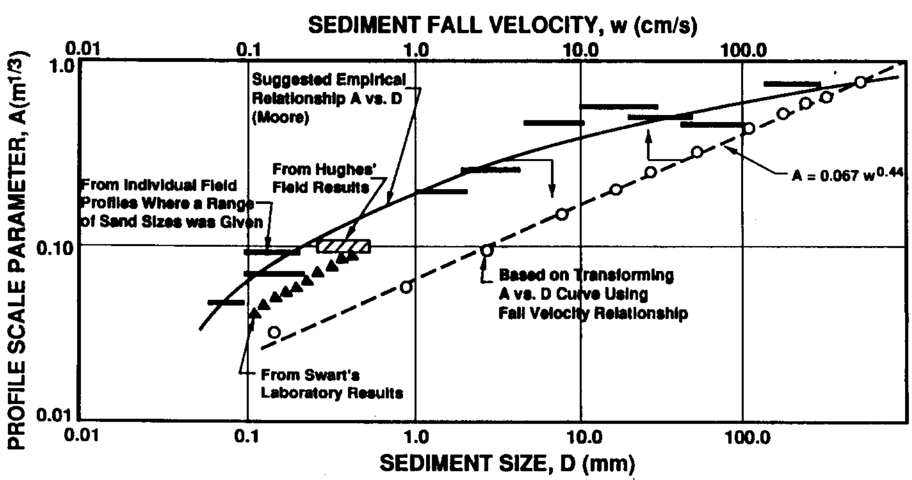


Fig. 2. Beach profile factor, A, vs. sediment diameter D, and fall velocity, w, in relationship $h=Ax^{2/3}$ (Dean, 1987; modified from Moore, 1982).

the resulting equilibrium profile form (expressed in terms consistent with usage here) is:

$$y=\frac{h}{BSL}+\frac{h^{3/2}}{A^{3/2}} \quad (4)$$

which has a non-zero *uniform* slope, *BSL*, near the water line and in deeper water approaches Eq. 1. In this paper, we will refer to the first term on the right hand side of Eq. 4 as the "gravity term" as it dominates in those portions of the profile where the slopes are greater and hence gravity is most significant.

Equation 1 is applicable for the case of uniform sediment size across the surf zone and is the result of integrating the following differential equation:

$$h^{1/2}\frac{dh}{dy}=\frac{2}{3}A^{3/2} \quad (5)$$

This latter equation provides a basis for predicting equilibrium profiles with a cross-shore variation in sediment textural characteristics which is normally the case in nature. The counterpart to Eq. 5 in which the gravity terms is included is:

$$\frac{dh}{dy}=\left(\frac{1}{BSL}+\frac{3}{2}\frac{h^{1/2}}{A^{3/2}}\right)^{-1} \quad (6)$$

Various approaches exist for predicting the EBP for the case of non-uniform sediment size and thus non-uniform A parameter as described in Dean (1991), Larson (1991) and Work and Dean (1991). In the simplest case in which A can be represented as piece-wise uniform, say between y_n and y_{n+1}, it can be shown that h can be represented as:

$$y=y_n+\frac{h-h_n}{BSL}+\frac{h^{3/2}-h_n^{3/2}}{A_n^{3/2}} \quad (7)$$

which applies for $y_n<y<y_n+{}_1$.

In the application here, the sediment characteristics had been obtained by sampling at various points, y_n, across the profile. These mean diameters were first transformed to A values and it was considered that the A values varied linearly between the two known adjacent points, y_n and y_{n+1}. The equilibrium profile was obtained by integrating numerically as follows:

$$h(y_{i+1})=h(y_i)+\left(\frac{1}{BSL}+\frac{3}{2}\frac{h_i^{1/2}}{\bar{A}^{3/2}}\right)^{-1}(y_{i+1}-y_i) \quad (8)$$

in which:

$$\bar{A}=A_n+\left(\frac{A_{n+1}-A_n}{y_{n+1}-y_n}\right)\left(\frac{y_{i+1}+y_i}{2}-y_n\right) \quad (9)$$

and it is noted that $y_n<y_i$, $y_{i+1}<y_{n+1}$. In the applications here, $y_{i+1}-y_i$ was taken as 1 m. The values of the beach face slope, BSL, were based on profile measurements where such data were available. Lacking measurements, values were based on the nearest available data.

Our first attempts in developing and comparing profiles did not include the beach face slope term. However, it became apparent that fairly consistent differences existed which suggested the need to include this term. The significance of incorporating cross-shore variation in sediment size is, as yet, unresolved. Studies employing methods similar to those here report contrasting results. For example, Larson (1991) found profiles were "more accurately described" whereas Work and Dean (1991) concluded results were "not drastically improved". Intuitively, such analyses would be most beneficial where the variation in sediment size is large.

Interpretation of profile differences

The predicted profiles were developed as described in the preceding section and were compared with the measured profiles. The differences were interpreted in terms of several process elements. Although the comparison is on a profile-by-profile basis, some of the differences could be due to gradients in longshore transport. Several of the characteristics of the expected differences between measured and predicted profiles and their interpretation are discussed below.

Case I. Profiles with an excess or deficit of sediment

The simplest case is one in which the profile contains an excess or deficit of sediment relative to the predicted equilibrium profile. These cases are illustrated as A (Excess), B (Equilibrium) and C (Deficit) in Fig. 3a. *If* only cross-shore sediment transport is involved, the interpretation is that, over the long-term, sand will be transported landward over the profile with an excess of sediment

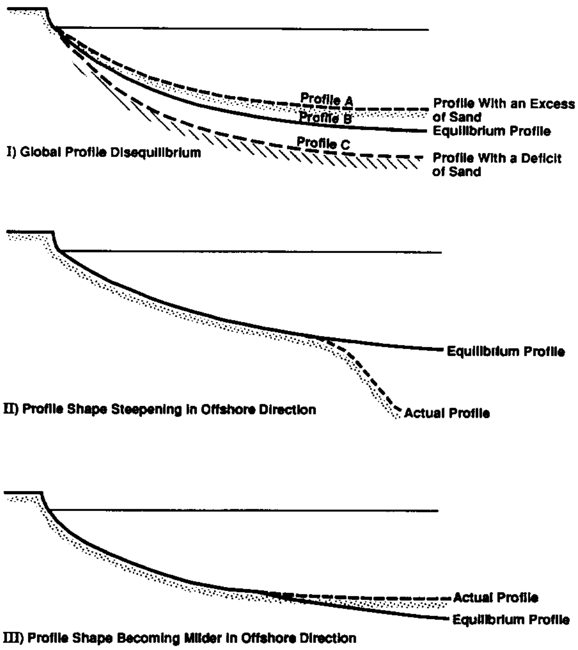


Fig. 3. Characteristic shapes of beach profiles which are out of equilibrium.

(Profile A) inducing a long-term tendency for shoreline advancement, and vice versa for the profile with a deficit of sediment.

Case II. Profiles transitioning to steeper slopes in the seaward direction

The interpretation of this feature, illustrated in Fig. 3b, can be ambiguous. One possibility considers the change to a greater slope as representing the transition from an "active" to "inactive" region. Thus, this would correspond to something like the depth of limiting motion. A second interpretation is that the sediment forming that portion of the beach profile which is in near-equilibrium is derived from a nearshore excess which could include terrigeneous sources or gradients (convergences) in longshore sediment transport and the transition in slope is actively translating seaward. In either case, the probable dominant processes have resulted, or are resulting, in an excess of sediment in the shallow nearshore zone with the sediment reworked in the cross-shore to approach equilibrium. It is noted that in some respects, this case is similar to profile adjustments following beach nourishment.

Case III. Profiles transitioning to milder slopes in the seaward direction

This characteristic, illustrated in Fig. 3c, is interpreted as representing either: (a) if the transition is relatively gradual, a profile which was likely constructed (at least in part) by onshore sediment transport with long-term shoreward transport continuing, or (b) if the transition is abrupt, a profile which was likely constructed by seaward transport from sediment sources in the nearshore zone, not dissimilar to Case II but with the profile advancing into water which is shallower than the equilibrium. The latter interpretation requires the sediment in the advancing profile to be coarser than that in the underlying profile (Dean, 1991).

Local equilibrium considerations

The above discussion has centered on identification of the profile disequilibrium through characterization of the entire profile. Inspection of the basis for equilibrium (Eq. 6) demonstrates that local equilibrium requires:

$$\left(\frac{1}{BSL}+\frac{3}{2}\frac{h^{1/2}}{A^{3/2}}\right)\frac{\mathrm{d}h}{\mathrm{d}y}=1 \tag{10}$$

Since the second term in the parenthesis is usually dominant in all but the shallowest water depths, if corresponding depths on the actual and equilibrium profiles have the same shape, the profile is in local equilibrium, i.e., corresponding depths *do not* need to be located at the same offshore distance. Inshore profile portions that are not in equilibrium will result in a horizontal (y) separation of seaward portions of the profile *even if they are* in equilibrium. Figure 4 provides an example.

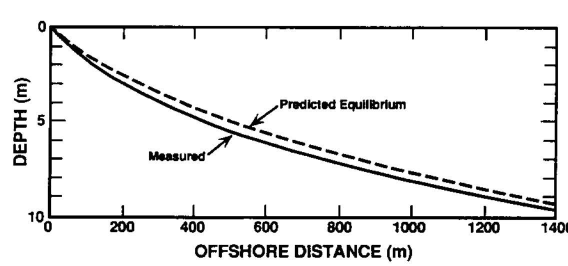


Fig. 4. Illustration of measured profile in equilibrium over the depth range, 5 m $<h<$ 9 m, even though profiles are displaced horizontally.

Degree of profile disequilibrium

It is useful to quantify the degree of profile disequilibrium. One approach is to consider the volume difference above some depth, h_*, to be rectified by a shoreline shift, Δy, with the resulting profile to be of equilibrium form. The resulting approximate shoreline displacement, Δy is:

$$\Delta y \approx \frac{V_{\mathrm{equil}} - V_{\mathrm{actual}}}{h_* + B} \quad (11)$$

in which B is the berm height, V_{equil} and V_{actual} are the volumes between mean sea level and the equilibrium and actual profiles, respectively, out to the common end of line. In cases where the depths on either profile exceed h_*, their value in the volume computations is replaced by h_*. The quantity, h_*, as used here represents a reference depth above which equilibration of sediment volumes is considered. It need not represent the depth of limiting motion. It is noted that $\Delta y > 0$ implies an excess of sediment in the actual profile and vice versa for $\Delta y < 0$.

Discussion of the concept of the depth limiting motion

The preceding discussion of response times for increasing water depths is somewhat contradictory to the concept of the depth of limiting motion often used by coastal engineers and geologists and thus may merit elaboration.

The concept of the depth of limiting motion is extremely useful in engineering problems such as shoreline retreat due to sea-level rise (Bruun, 1962) and beach nourishment (Dean, 1991). Several studies have been conducted to quantify this depth. Hallermeier (1981) developed the following relationship for the seaward depth, h_1, interpreted by him as the occurrence of "sand motion by usual waves, so that significant onshore–offshore transport is restricted to water depths less than h_1", where

$$h_1 = (\bar{H}s - 0.3\sigma)\bar{T}_s(g/5000D)^{0.5} \quad (12)$$

in which $\bar{H}_s$ is the annual mean significant wave height, σ is the annual standard deviation in significant wave height, $\bar{T}_s$ is the annual mean significant wave period, g is the gravitational constant, and D is the median sand diameter, all in consistent units.

From engineering considerations, beach profile response is usually expressed in terms of equilibria and thus the concept of limiting depth is useful as it forms one boundary of a closed system and renders the problem tractable. Realizing that most engineering projects have an associated "design life", the concept of depth of limiting motion and the continuum of response times over a wide range of depths as portrayed in Fig. 1 become much more consistent. Since the motions and changes in the greater water depths occur so slowly, it is neither necessary nor realistic to include consideration of these depths in the design or evaluation considerations of engineering projects. Reference to the design problem of a beach nourishment project will serve as further illustration. Placement of sediment in a beach nourishment project usually establishes a disequilibrium in both the planform and profile. Depending on the dimensions of the project, initial responses can be fairly rapid in both dimensions. However, for most project geometries, the profile approaches equilibrium relatively rapidly, say within two to five years to the state where further adjustments toward equilibrium are caused only by the more significant storm events. By contrast, the time scale for planform equilibrium for relatively long projects (say 5 to 10 km) is on the order of decades and continues, albeit at an increasingly lower rate, even for the smaller waves. Furthermore, these time scales are such that, due to the dominant transport causing the planform evolution to be concentrated in shallow water, the associated recession of the upper portions of the beach profile coupled with the earlier phases of the profile equilibration, cause a reversal in the *direction* of profile equilibrium related transport for the lower contours, i.e., toward shore. This is illustrated schematically in Fig. 5.

Relevant geological background of the New Zealand beaches

New Zealand is relatively young geologically, and the central and northeastern North Island

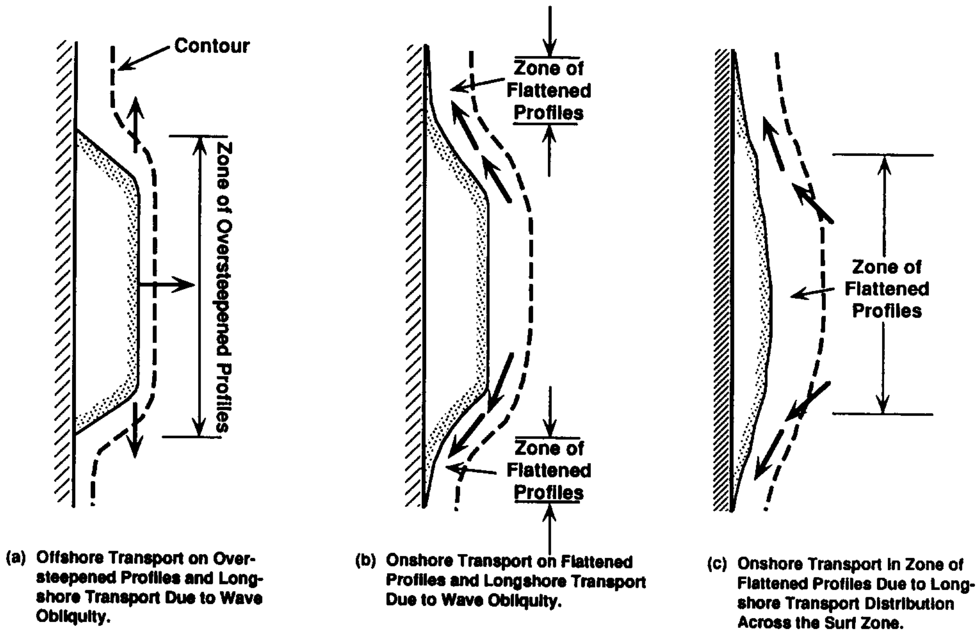


Fig. 5. Three phases of observed sediment transport in vicinity of nourished projects. *Note*: cross contour transport due to profile disequilibrium.

coast, from whence the beach profiles described in this paper were obtained, has undergone extensive coastal deposition in the late Pleistocene and Holocene. The North Island is characterized by volcanism and tectonism associated with the Pacific plate boundary and subduction zone. Thus the coastline and shelf possess relatively steep slopes. But the central North Island rhyolitic volcanism producing a prodigious supply of pumiceous sands, taken in conjunction with the steep catchments and swift flowing rivers in easily erodible lithologies, episodic extreme rainfall events, and the embayed nature of the northeast coast are all factors that have contributed to substantial progradation in the embayments (Pullar and Selby, 1971; Healy and Kirk, 1982; Richmond et al., 1984). Certainly in the Pleistocene there appears to have been an excess of sediment on many of the New Zealand continental shelves resulting in a pervasive landward sediment flux across the continental shelf into the nearshore system (Healy et al., 1976). There is evidence from a number of locations (Schofield, 1970; Harray and Healy, 1978) that this excess was the result of sediments carried to the shelves before the post-glacial transgression reached its approximate present level about 6000 years ago.

Data and analysis results

Data

Beach profiles and associated sediment characteristics presented herein for the North Island of New Zealand were obtained primarily from published sources and new data (one profile) obtained through a field program.

The field efforts were relatively straightforward and included application of standard rod-and-level surveying techniques out to approximately 2 m water depth at low tide combined with fairly simple but effective offshore surveys at high tide. The latter consisted of using a Magellan Global Positioning System (GPS) for horizontal position, a lead line for obtaining depths and a "dredge" sediment sampler. At each location, the boat was anchored, the location established with the GPS and the depth and bottom sample taken. The GPS is generally accurate to ± 30 m (Magellan Systems Corporation, 1989) which we verified by testing over a transect of known distances. The origin of the baseline was also referenced with the GPS, thereby allowing the offshore measurements to be "tied" to the portion established by rod and level techniques. The tide level for correction of the lead line soundings was based on leveling to the water line during the beach profiles and correcting the lead line data based on the predicted tides. This procedure was checked through overlap between the two profile segments.

Table 1 and Fig. 6 present the locations of the ten profiles, the sources of the data and the values of the shoreline shift, Δy, for values of $B = 1.5$ m and $h_* = 7$ m.

Analysis and results

Individual profiles

The comparisons for each of the ten profiles are presented in Fig. 7a through j. As noted previously, the equilibrium shoreline adjustments, Δy, in Table 1 are for values of $h_* = 7$ m, and $B = 1.5$ m in Eq. 11. This does not imply that 7 m is an appropriate depth of limiting motion. Rather this depth was common to all profiles and thus provided a consistent basis for comparison. The quantity B is the average berm height determined from the profile data.

Although the basis for the equilibrium profile theory (Eq. 4) implies applicability only within the surf zone, profiles have been calculated to the seaward limits of the available measured profile and sediment data. Offshore distances and depths ranged up to 2300 and 24 m, respectively. Inspection of Fig. 7 indicates that compared to the measured, the calculated profiles are significantly deeper in two cases (Fig. 7a and g), shallower in four cases (Fig. 7c, e, i and j) and in reasonable agreement in four cases (Fig. 7b, d, f and h). In two of the measured profiles (Fig. 7c and d), substantial bars are present which cannot be represented by the EBP theory. The number of sediment samples available for each profile ranged from three to twelve. There is not a clear correlation between agreement and number of sediment samples available. As might be expected, the profiles generally tend to deviate with increasing distance from shore. For water depths less than 5 m, the profiles were in generally reasonable agreement as discussed in greater detail later. Beach sand mining has occurred at profiles in Fig. 7e and h and nearshore mining at the profile in Fig. 7j. All three profiles are characterized by negative Δy values; however, the differences in equilibrium and

TABLE 1

Profile characteristics and analysis results

Figure No.	Location name	Data sources[a]	Number of sediment samples	Size range (ϕ)	Beach face slope (BSL)	Δy (m) for $h_* = 7$ m
7a	Ohiwa	1,1,2	3	2.4–3.1	0.048	158.8
7b	Ohope	1,1,2	3	2.4–3.3	0.063	22.4
7c	Piripai	1,1,3	3	1.4–3.2	0.064	−43.4
7d	Matata	1,1,3	3	0.6–2.6	0.073	47.9
7e	Papamoa	1,1,3	3	2.0–2.9	0.055	−53.1
7f	Mt. Maunganui	4,4,4	10	0.70–2.51	0.077	−28.7
7g	Waihi	5,1 & 6,2	9	2.00–2.85	0.038	138.1
7h	Whiritoa	7,8 & 9,7	4	1.25–2.80	0.072	−79.5
7i	Omaha	our data	10	1.69–2.33	0.031	−104.6
7j	Pakiri	10,10,our data,	12	1.04–2.03	0.056	−71.1

[a]Representing profile, sediment data and BSL, respectively, where: 1 = Healy et al. (1976); 2 = Healy (1978); 3 = average of Healy (1978) and our own data; 4 = Foster (1991); 5 = Harray (1977); 6 = Bradshaw (1991); 7 = Healy et al. (1981); 8 = Healy and Dell (1982); 9 = Christopherson (1977); 10 = Hilton (1990).

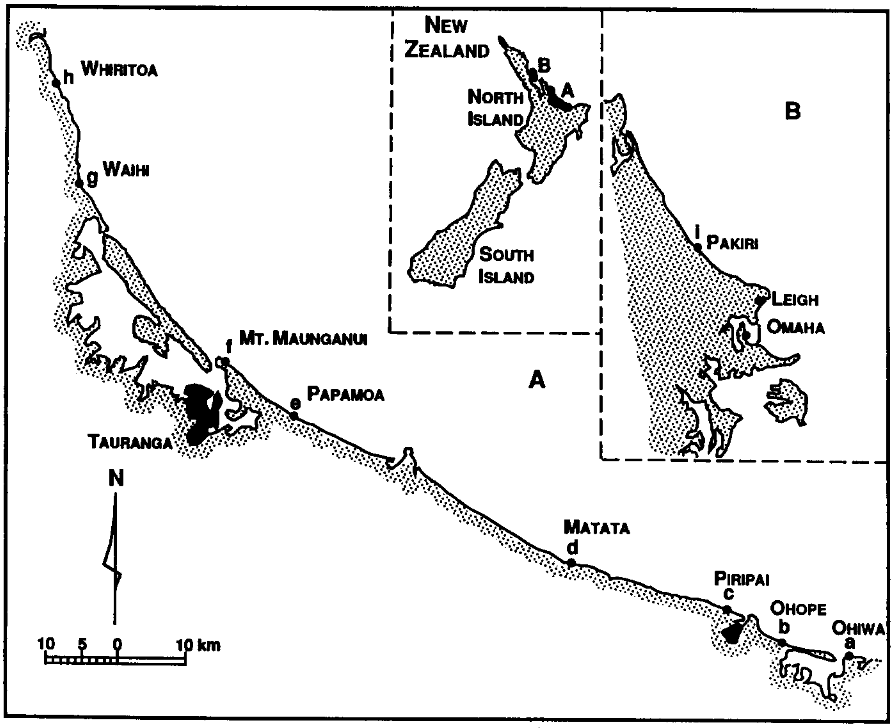


Fig. 6. Location map of measured profiles, North Island, New Zealand.

measured profile forms in Fig. 7e and h are not consistent with extraction from the beach. Moreover, the volumes removed from the profile in Fig. 7j, although undocumented, are not believed to be large enough to account for the large differences.

The values of shoreline adjustment, Δy, required to achieve volumetric equilibrium, shown in Table 1, range from a recession of m to advancement of 158 m. Six of the values are negative.

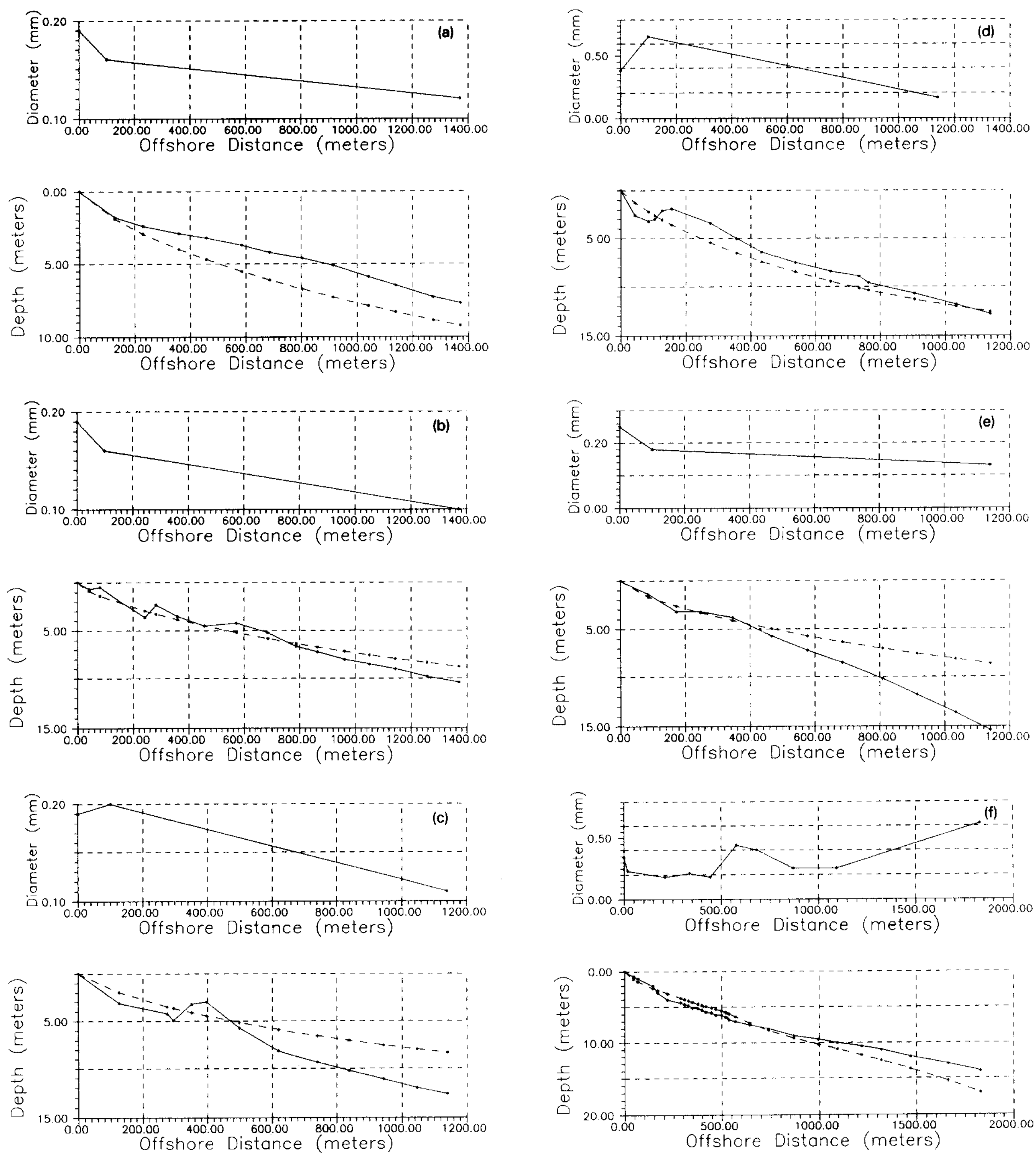
Grouped profiles

Two additional comparisons were made between measured and predicted profiles. In order for the comparisons to be meaningful, the predicted depths were first established at the same locations of the measured depths for each of the ten profiles, i.e. as shown in Fig. 7. The depths at ten meter cross-shore intervals were then interpolated from the points where measured depths were available. These interpolated, measured and predicted depths obtained in the same manner were then used in the comparisons described below.

Average of measured and predicted profiles

Figure 8 compares the averages of the ten measured and predicted profiles. It is seen that on the average, the two profiles are in quite good agreement out to water depths of 5 m or so. For greater water depths, the depths of the actual profile exceed those of the predicted. At the end of the profiles (at 1130 m from shore) the two differ by slightly less than 2 m. Within the equilibrium profile hypothesis there are two possibilities to the interpretation of the difference in Fig. 8. As shown in Fig. 3a, this could be interpreted as a profile with a deficit of sand. Indeed this would be the interpretation of applying Eq. 11 to these average profiles. The second interpretation follows that illustrated in Fig. 3b, in which sediment is being supplied to the shallow water region through sediment transport convergence and due to the shorter time scales in these water depths, the profile is in reasonable equilibrium there. The profile is advancing over a surface that was in near-equilibrium with a shoreline at a more landward location. Because of the geological history and processes of the New Zealand shoreline, we believe the latter interpretation to be the more appropriate.

Inspection of Fig. 7j demonstrates that for reasons unknown, the deviation between the measured and predicted profiles at Pakiri is unusually



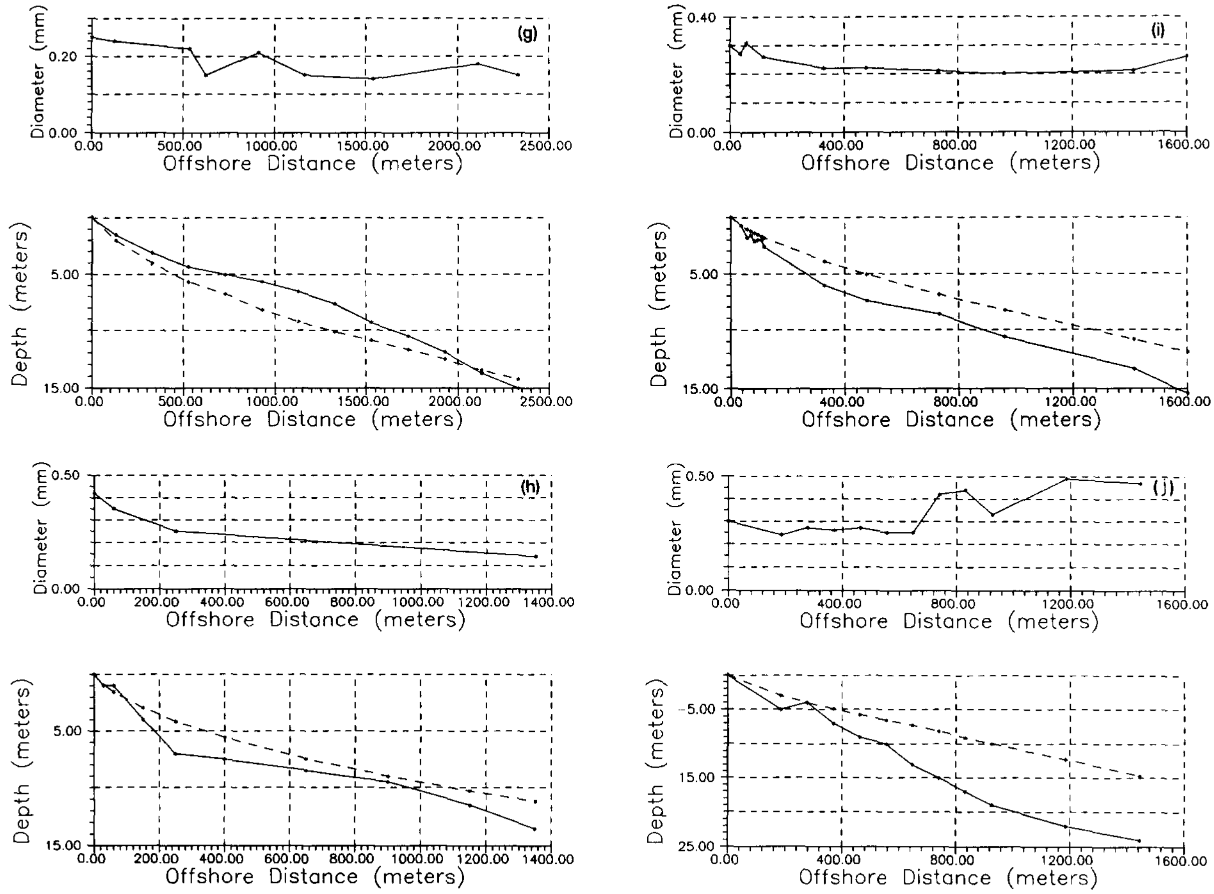


Fig. 7. Measured sediment sizes and comparison of measured and predicted profiles. Measured = Solid Line, Predicted = Dashed Line. (a) Ohiwa Beach; $BSL = 0.048$. (b) Ohope Beach; $BSL = 0.063$. (c) Piripai Beach; $BSL = 0.064$. (d) Matata Beach; $BSL = 0.073$. (e) Papamoa Beach; $BSL = 0.055$. (f) Mt. Maunganui Beach; $BSL = 0.077$. (g) Waihi Beach; $BSL = 0.038$. (h) Whiritoa Beach South; $BSL = 0.072$. (i) Omaha Beach; $BSL = 0.031$. (j) Pakiri Beach; $BSL = 0.056$.

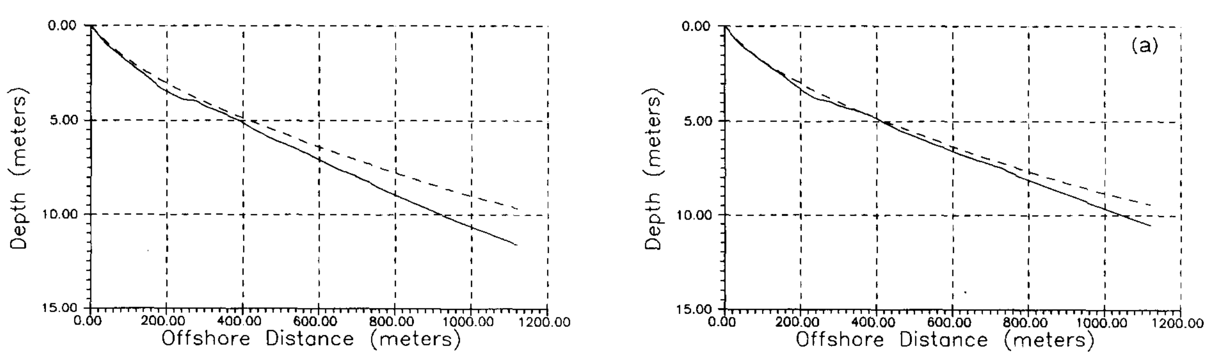


Fig. 8. Comparison of average measured profile (solid line) and predicted profile (dashed line). Total of ten profiles. (a) Total of nine profiles (without Pakiri profile).

large. Therefore, the average profiles were calculated excluding the Pakiri beach profiles. The results are presented in Fig. 8a, where, as expected, the agreement is much better. The *average* depths agree within 1.1 m for all offshore distances.

Goodness of fits

The question could be asked whether the equilibrium beach profile method is an improvement over other approaches. First with the limited data available, there is no other approach to calculating, in a "blind-folded" manner, the equilibrium beach profiles. However, the following comparison was made in an attempt to address the question of whether using the average of the measured profiles is as good or better than the predicted profiles as representations of the actual profiles. The average of the ten measured profiles was calculated at each point and the variance about that average calculated. The running variance from shore seaward was then calculated from which the standard deviation was determined. The same approach was applied to the predicted profiles, except the standard deviation was based on the differences between the measured and predicted profiles at each point. The results are presented in Fig. 9 where it is seen that on an overall basis, the standard deviation between the predicted and measured profiles is slightly less than between the measured profiles and their local average.

The goodness of fit calculations were repeated excluding the Pakiri profile; the results are presented in Fig. 9a. For the inshore 500 m, there is very little change in the two standard deviation curves. However, farther offshore, where the Pakiri profiles deviate most, a substantial reduction occurs when excluding the Pakiri data. The relative fits between measured and predicted profiles, however, is not affected significantly.

Summary and conclusions

Summary

Results have been presented describing a "blind-folded" comparison of measured profiles with calculated equilibrium beach profiles using established techniques (Dean, 1991), based on the measured beach face slope, and the sediment size distribution across the profile. Additionally, procedures have been described for interpreting profiles which are globally or locally out of equilibrium.

The comparison includes ten profiles from the northeastern coast of New Zealand. For most of the profiles, only three sediment samples were available. For four of the profiles, nine or more samples described the cross-shore sediment distribution. A fairly wide range of sediment sizes existed.

Although comparisons of individual calculated and measured profiles showed substantial differences, the average profiles were in good general agreement, especially in water depths less than 5 m. This is consistent with the surf zone region of extreme waves. The equilibrium profiles calculated by the "blind-folded" method produced slightly lower deviations from the individual measured profiles than the individual measured profiles from

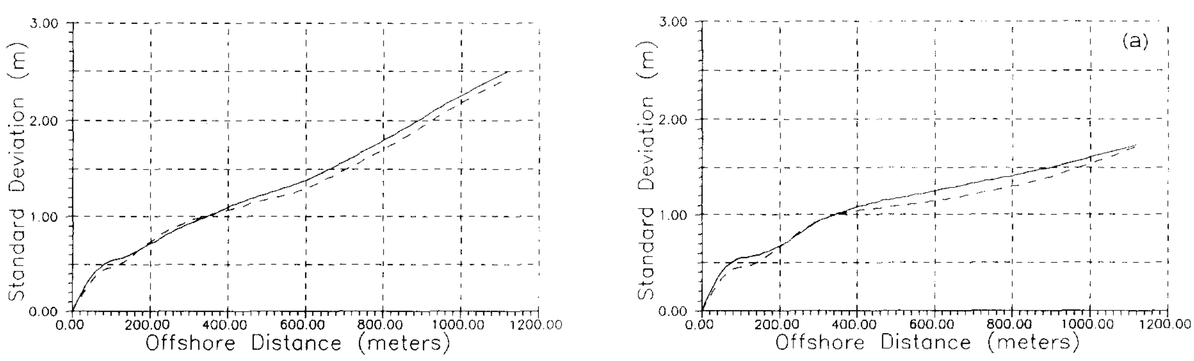


Fig. 9. Comparisons of running standard deviations between measured profiles and their average at each point (solid line) and the measured and calculated profiles at each point (dashed line). Total of ten profiles. (a) Total of nine profiles.

their local average. This suggests that the equilibrium profile theory is effective to some degree in reflecting profile characteristics due to sediment size variations.

Conclusions

The comparisons provide generally encouraging correspondence between the measured and calculated profiles. The measured profiles vary consistently with the variation of grain size as predicted by the equilibrium profile methodology.

The interpretation suggests that four of the ten profiles contain an excess of sand. Three of the remaining six with a deficit of sand have been or currently are sites of active sand mining; however, it is not believed that the sand mining is totally responsible for the deficits apparent in these profiles.

In calculating equilibrium beach profiles, it is necessary to include the "gravity" term (see Eq. 4). More results of the type described here to substantiate and/or modify the equilibrium beach profile are required before the results of apparent disequilibrium can be interpreted with confidence.

In general it is not possible to state whether differences identified between measured and predicted profiles are due to profile disequilibrium or limitations in present knowledge of equilibrium beach profiles. Most probably the differences reflect a combination of these two causes. The simple method applied here does not attempt to represent the complex nearshore hydrodynamic flows.

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