Journal of Coastal Research	7	4	1139–1152	Fort Lauderdale, Florida	Fall 1991

Wave Runup Distributions on Natural Beaches

Peter Nielsen[†], **and David J. Hanslow**

Coast and Rivers Branch
Public Works Department
1 Chifley Square
Sydney, New South Wales
2000, Australia

ABSTRACT

NIELSEN, P. and HANSLOW, D.J., 1991. Wave runup distributions on natural beaches. *Journal of Coastal Research*, 7(4), 1139–1152. Fort Lauderdale (Florida). ISSN 0749-0208.

Runup distributions were measured on a wide spectrum of sandy beaches on the coast of New South Wales, Australia. The data indicates that the Rayleigh distribution is a reasonable statistical model for the maximum level reached by individual waves. The vertical scale of the best-fit distribution is proportional to the wave height times the surf similarity parameter for the steeper beaches in accordance with Hunt's formula for runup of regular waves on structures. For flat beaches, however, the vertical scale of the distribution is independent of the beach slope. The base level for the best-fit distribution (*i.e.* the highest level transgressed by all incoming wave crests) is indistinguishable from the still water level on the steep beaches but significantly lower on flat beaches. The demarcation between "steep" and "flat" beaches in these respects is at a beach face slope of approximately 0.10. The level of the shoreline relative to the runup distribution is a decreasing function of the beach slope.

ADDITIONAL INDEX WORDS: *Wave runup, wave setup, swash, surf zones.*

INTRODUCTION

The process of wave runup or swash has a very direct impact on coastal structures and protection works. Consequently, the study of runup has received considerable attention by researchers over recent years. The complexities of nearshore wave/wave interactions and of nearshore processes in general has meant that most progress in the study of runup has been made on an empirical basis.

Early studies suggested the usefulness of the surf similarity parameter or Iribarren number for the quantification of many nearshore processes including wave runup (Iribarren and Nogales, 1949; Battjes, 1971). Experiments under a range of incident wave conditions have since confirmed this usefulness particularly with respect to runup height (Guza and Thornton, 1981; Holman and Sallenger, 1985).

The aim of the present study is to examine runup distributions from a range of natural beach types (reflective through to dissipative) and to provide a comprehensive picture of wave runup distributions on natural beaches as they vary with beach morphology.

The present study is part of an integrated project examining the processes of wave setup, wave runup and the coastal watertable as indicated in Figure 1. Information relating to wave runup distributions as well as the shoreline position have been collected from a range of natural beach types. The shoreline is defined as the line where the mean water surface (MWS) intersects the beach face (Figure 2).

Most of the concepts and definitions relating wave setup and runup used in this paper are as discussed in Nielsen (1988, 1989).

FIELD SITES

Data have been collected for the present study from 6 beaches on the coast of New South Wales, Australia (Figure 3). These beaches were selected because they represent a wide cross section of natural sandy beach types, ranging from the highly reflective steep beach type (Pearl Beach) to the dissipative low gradient beach type (Seven Mile Beach).

The New South Wales coast has a highly variable wave climate enabling the collection of data over a wide range of incident wave condi-

90139 received 20 November 1990; accepted in revision 5 April 1991.
[†]*Present Address: Department of Civil Engineering, University of Queensland, St. Lucia, Queensland 4072, Australia.*

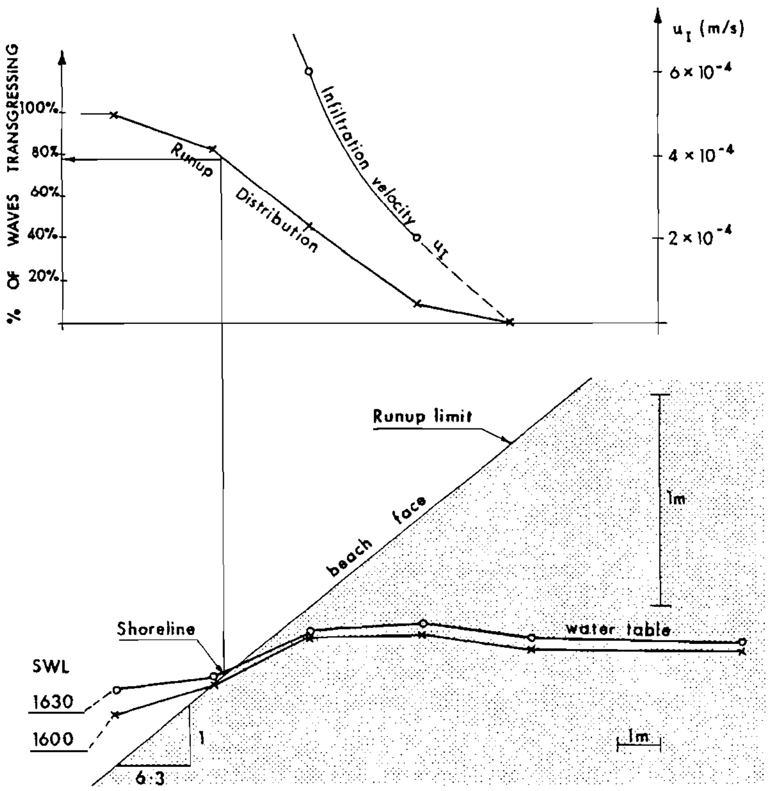

Figure 1. Two positions of the mean water surface, MWS measured with 30 minute interval on April 18, 1989 at Palm Beach, north of Sydney. Above is shown the exceedence (transgression) distribution for runup during this time interval. The shoreline, *i.e.* the intersection between the MWS and the sand, is seen to be transgressed by about 78% of the waves in this case.

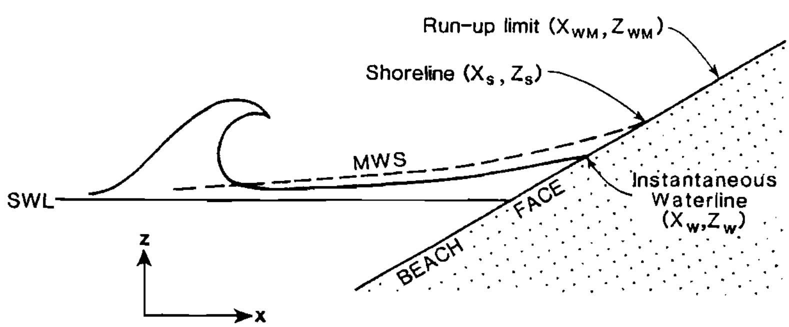

Figure 2. Definition diagram for the instantaneous water surface parameters; the still water level, SWL; the mean water surface, MWS; and the shoreline.

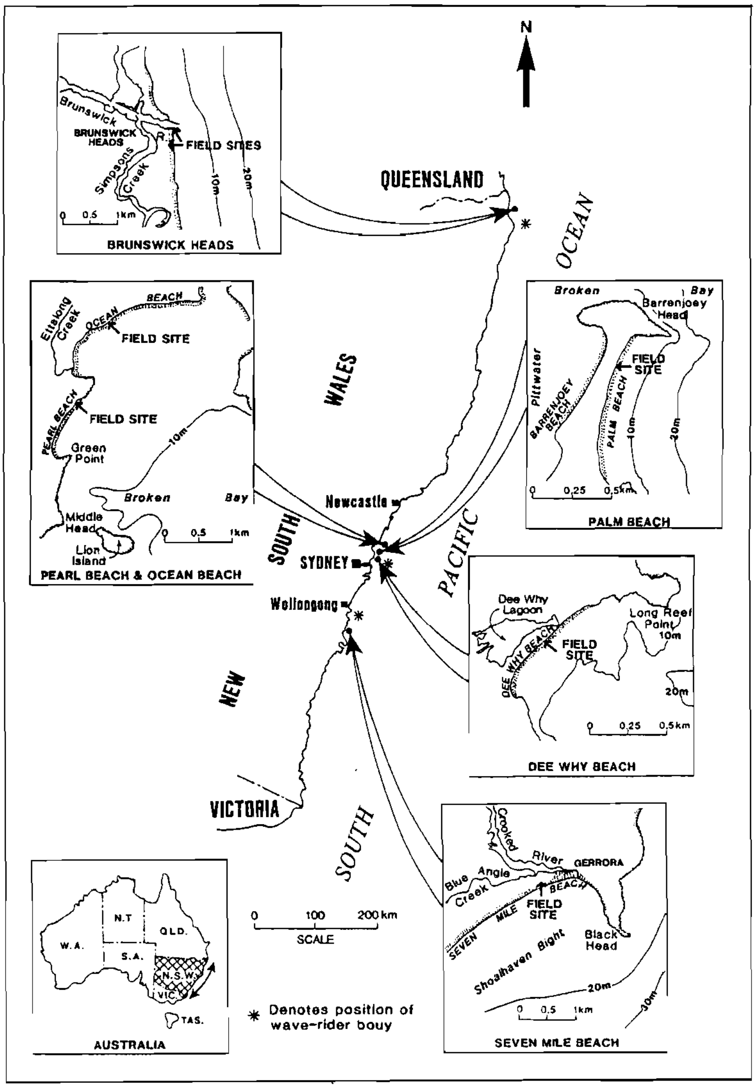

Figure 3. Field sites on the New South Wales coast, Australia. "*" mark the positions of offshore wave rider buoys in approximately 80 metres of water.

tions. The present data were collected over a wave height range (Deep water root mean square wave height, H_{orms}) of 0.53 m to 3.76 m and a wave period range (significant period, T_s = period of highest ⅓ of waves) of 6.4s to 11.5s. Wave data were obtained from deep water (approx 80 m) wave rider buoys located off the coast within less than 30 km from each field site. Tidal range for the region varies from about 2 m at springs to less than 1 m at neaps.

The field sites are shown in Figure 3. They include Seven Mile Beach, Dee Why Beach, Palm Beach, Pearl Beach, Ocean Beach and Brunswick Beach. Seven Mile Beach is located within Shoalhaven Bight on the south coast of New South Wales. The Field site at the northern end of the beach was chosen because of its fine sand (mean swash zone grain size is approximately 0.18 mm) and correspondingly dissipative topography. Beach face and surf zone slopes are generally very low gradient with only subtle nearshore bars.

Dee Why Beach is located just north of Sydney. The mean swash zone grain size on this beach is of the order 0.5 mm. The surf zone is generally characterised by rhythmic topography with crescentic or transverse bars and regular rip channels. The beach state may, however, range from a reflective state with cusps after extended periods of low waves to a more dissipative bar/trough system after storms.

Palm Beach is located approximately 25 km north of Sydney. This beach has medium to coarse sand (mean swash zone grain size is approximately 0.4 mm) and is characterised by a generally reflective beach face with cusps. The surf zone topography is generally rhythmic with periodic bars and rip cells present but may tend towards ridge/runnel type topography after extended periods of small waves.

Pearl Beach is located within Broken Bay about 30 km north of Sydney. This beach represents the reflective extreme among sandy beaches in New South Wales. Mean Swash zone grain size is on the order of 0.8 mm and the beach is always reflective with well developed cusps and no nearshore bars (*e.g.* HUGHES and COWELL, 1987; BRYANT, 1982).

Ocean Beach is also located within broken bay, immediately north of Pearl Beach. This beach is composed of fine sand (mean grain size is approximately 0.21 mm). Nearshore topography is generally dissipative with low gradient slopes across both the surf zone and the beach face. The nearshore profile is generally characterised by subtle bar/trough type topography with some alongshore variability.

Brunswick Beach is located on the north coast of New South Wales approximately 40 km south of the Queensland border. The field site is located approximately 150 m south of the southern breakwater which forms the entrance to the Brunswick River. The beach runs uninterrupted to the south for approximately 12 km. Mean grain size on the beach is on the order of 0.22 mm and the topography is generally dissipative. Surf zone topography is usually characterised by a well developed longshore bar trough system. Most of the time a boundary rip current runs along the breakwater to the north of the field site, and small rip cells may occur in conjunction with the landward migration of the inner bars during periods of small waves.

BACKGROUND

The process of wave runup or swash is the motion of the water line up and down the beach face as quantified by $x_w(t)$ and $z_w(t)$ (Figure 2). The term has been used loosely in the literature to refer to the maximum level of the water line, but for clarity the term runup is reserved for the process in the following. The maximum water line elevation z_w reached by an individual wave is called z_{wm}.

The process of wave runup takes on very different physical appearances depending on the values of such parameters as beach slope, wave steepness, slope roughness, and slope permeability.

For some combinations of these parameters, the waves will break on the slope, while for others, they will not. IRIBARREN and NOGALES (1949) demonstrated that it is mainly the combination of beach slope and wave steepness, which determines whether the waves break or not. Subsequently, BATTJES (1971) put their criterion on the form:

The waves will not break if

$$Ho/Lo < 0.19 \tan^2\beta$$

The waves will break if (1)

$$Ho/Lo > 0.19 \tan^2\beta$$

where H_o is the deep water wave height, L_o is the deepwater wave length and $\tan\beta$ is the beach slope. Correspondingly, the Iribarren Number of Surf similarity parameter

$$\xi = (L_o/H_o)^{0.5} \tan\beta \quad (2)$$

has proven a useful parameter for describing the overall characteristics of a surf zone.

Most of the laboratory work on wave runup has been aimed at the design of breakwaters and other structures and the test profiles have generally consisted of two straight sections *i.e.*, a deep section of uniform depth where the waves did not break, followed by a fairly steep, straight slope. The primary additional difficulty presented by natural beaches is therefore that the meaning of the term "beach slope" is not trivial (see Figure 4). Various representative slopes may be defined for complicated beach profiles, for example the slope $\tan\beta_F$ of the beach face which is generally fairly straight, or the average slope $\tan\beta_H$ for the section between the runup limit and the point where the still water depth equals the wave height, D = H.

For dissipative beaches this problem may not be as pronounced as the difference between beach face slope and overall nearshore slope is usually fairly small and nearshore topographic features are subtle. For intermediate to reflective beach types the problem is, however, significant with large variations between beach face slope and general surf zone slope. For intermediate beaches the presence of bars complicates the picture significantly and choice of an appropriate slope becomes difficult. For these beach types beach face slopes may be very steep, however the presence of bars makes them significantly different from the perennially reflective beaches like Pearl Beach. Steeper beaches also tend to be more subject to alongshore slope variations due to the presence of cusps.

The ideal measure of beach slope in relation to the runup processes should account for the whole history of wave deformation and breaking through the outer surf zone as well as for the slope of the beach face. However, the dynamics of breaking waves are not fully understood particularly in the presence of complex topography, and in any case the surveying of the outer surf zone under high energy conditions is usually not possible. Therefore, in the following analysis, extensive use is made of the beach face slope $\tan\beta_F$ for the pragmatic reason that it is easy to measure even under storm conditions. Meanwhile, it is acknowledged that the slopes of various other parts of the surf zone will influence the runup distribution.

Runup of Non-Breaking Waves

For regular waves which do not break, linear wave theory leads to the following formula for the maximum water line elevation

$$z_{wm} = SWL + H\left(\frac{\pi/2}{\beta}\right)^{0.5} \quad (3)$$

see *e.g.* the review of LeMehaute *et al.* (1968). For a vertical wall with $\beta = \pi/2$ this equation leads to the familiar result z_{wm} = SWL + H for standing waves.

Runup of Breaking, Regular Waves

The case of breaking waves is much more difficult to model theoretically than the nonbreaking case. The models which have been developed so far fall into two main categories, where one is based on the consideration of bores

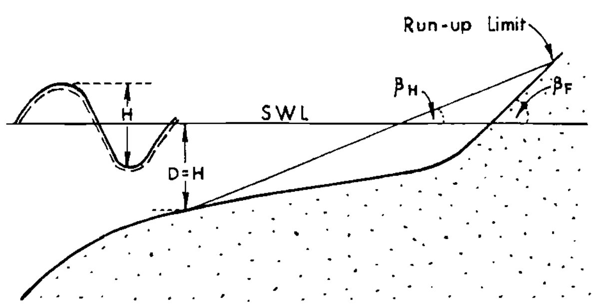

Figure 4. The term "beach slope" has no obvious meaning on natural, curved beach profiles, but the slope $\tan\beta_F$ of the beach face or the average slope $\tan\beta_H$ for the section between the runup limit and the point where D = H may be used as representative slopes. Here H is the wave height and D is the water depth.

and their collapse as they hit zero depth, and the other is based on non-saturated breaker theory. For a review, see LEMEHAUTE *et al.* (1968).

None of the theories for runup of breaking waves are very satisfactory, because the essential input parameters are unknown. These include the bore speed immediately before collapse and the influence of the backwash from the previous runup. However, a simple and fairly reliable empirical formula was given by HUNT (1959), and rewritten by BATTJES (1971) into the form

$$z_{wm} = SWL + H_o\xi_o = SWL + (H_oL_o)^{0.5} \tan\beta \qquad (4)$$

This formula is supported by numerous experimental studies apart from Hunt's own, see *e.g.* ROOS and BATTJES (1976). However, its validity is restricted to fairly steep slopes where the dissipation of energy by spilling breakers far from the shoreline is insignificant.

We note that while $z_{wm} - SWL$ is proportional to H for non-breaking waves, *cf* Equation (3), it grows only as $\sqrt{H}$ for breaking waves (Equation 4). The formulae above refer to periodic waves, but a recent data set presented by SYNOLAKIS (1987) shows that similar distinct regimes exist also for solitary waves and that the transition between these two regimes is quite sharp.

Apart from this empirical formula a recent numerical model developed by KOBAYASHI *et al.* (1989) also seems capable of predicting wave runup. This model has not however been verified for a wide range of natural beach types.

Effect of Wave Height Variability

Runup statistics related to irregular waves have been investigated theoretically by SAVILLE (1962), and by BATTJES (1971). Various runup distributions were obtained depending on the joint distribution assumed between wave height and period. For the special case of perfect correlation between H and T, Battjes found the resulting z_{wm} – distribution to be a Rayleigh distribution. That is

$$P\{z_{wm}>z\} = \exp\left[-\left(\frac{z-z_{100}}{L_{zwm}}\right)^2\right] \qquad (5)$$

where z_{100} is the highest level transgressed by 100% of the waves and L_{zwm} is the vertical scale of the distribution. Equation (5) is a reasonable approximation to most of the measured runup distributions even where Battjes' assumptions could not be expected to be fulfilled.

Both SAVILLE (1962) and BATTJES (1971) used the "hypothesis of equivalence" together with HUNT'S (1959) formula for the runup of regular waves which means that the level transgressed by n percent of the waves can be estimated from

$$z_{wmn} \approx (H_{on}L_o)^{0.5} \tan\beta + SWL \qquad (6)$$

for reasonably narrow banded waves, where H_{on} is the deep water wave height exceeded by n percent of the waves. It also implies that the vertical scale L_{zwm} which equals the rms value of $(z_{wm}-z_{100})$ can be estimated by

$$L_{zwm} \approx H_{orms}\xi_o = (H_{orms}L_o)^{0.5} \tan\beta \qquad (7)$$

where z_{100} is the highest point transgressed by all waves during the recording interval.

FIELD DATA ON WAVE RUNUP

The runup on beaches may be monitored in different ways depending on the general aim and the amount of detail required. Continuous records of the water line co-ordinates $\{x_w(t), z_w(t)\}$ can in principle be obtained by resistance runup meters or by down-looking cameras as applied by GUZA and THORNTON (1981) and by HOLMAN and SALLENGER (1985) respectively. The technique applied in the present study was simpler. Transgression statistics were obtained simply by counting the number n_i of waves running up past each of a number of stakes or other markers on the beach with known elevations z_i. The recording interval Δt was normally twenty minutes.

Because z_{wm} is expected to follow a Rayleigh distribution, the transgression statistics were plotted in such a way that the Rayleigh distribution corresponds to a straight line. That is, $\sqrt{(-\ln n_i/N)}$ was plotted against the scaled elevations, see Figure 5. N is the total number of waves expected during the recording interval ($N = \Delta t/T_s$), where T_s is the deep water significant wave period. Since the vertical scale was expected to be given by equation (7) the elevations were scaled on $(H_{orms}L_o)^{0.5}$. The beach slope was left out of the initial analysis because of the lack of a natural definition for it.

Linear regression analysis was then performed in accordance with

$$\sqrt{(-\ln n_i/N)} = \frac{z_i - SWL}{C_1\,(H_{orms}L_o)^{0.5}} + C_2 \qquad (8)$$

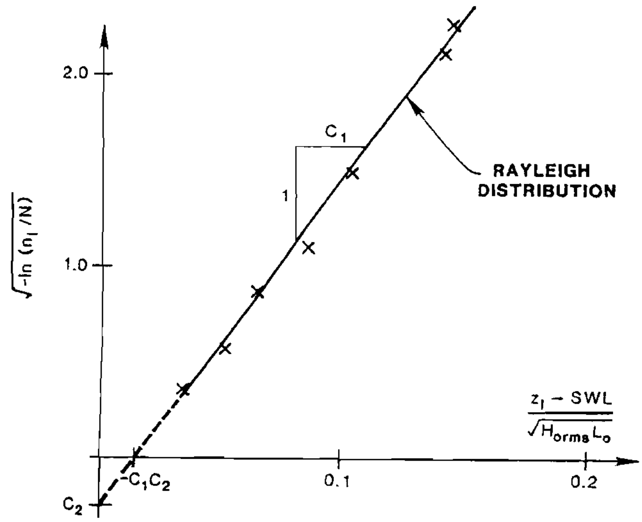

Figure 5. Runup data from Palm Beach 3/8-1990, 13:40–13:55. The Rayleigh distribution is seen to provide a reasonable model.

where C_1 plays the role of the beach slope in equation (7) and $-C_1C_2$ corresponds to the scaled elevation of z_{100} above the SWL; z_{100} is the highest point transgressed by all waves during the recording interval.

The data from the present study indicate that the Rayleigh distribution provides a reasonable description of the distribution of z_{wm} on a wide range of natural sandy beach types, ranging in beach face steepness from 0.026 to 0.19 or in other words covering the complete range from the reflective extreme, Pearl Beach, to the dissipative extreme, Seven Mile Beach. The lowest r-value from the linear regression analysis was 0.960. A summary of the runup data is provided in Table 1.

RESULTS

The Vertical Scale of the Runup Distribution

Hunt's Formula in the form of equation (7) provides a good indication of the vertical scale L_{zwm} for steep beaches; that is for $\tan\beta_F \gtrsim 0.10$, see Figure 6. However, the problem of defining the "beach slope" (*cf* Figure 4) is significant for these beaches. Using the slope of the beach face leads to the following rule of thumb

$$L_{zwm} \approx 0.6\ (H_{orms}L_o)^{0.5} \tan\beta_F \quad \text{for } \tan\beta_F \gtrsim 0.10 \qquad (9)$$

so the nominal beach slope for use with Hunt's formula for steep beaches is of the order 0.6 $\tan\beta_F$, *i.e.* considerably smaller than the slope of the beach face.

The next alternative is to use the average slope $\tan\beta_H$. It was not always possible to obtain the value of $\tan\beta_H$, but from the available data it seems that Hunt's formula with this average slope inserted provides a lower limit for L_{zwm} on steep beaches *i.e.*

$$L_{zwm} > (H_{orms}L_o)^{0.5} \tan\beta_H \quad \text{for } \tan\beta_F \gtrsim 0.10 \qquad (10)$$

For flat beaches the data indicates that the vertical scale of the distribution is no longer proportional to the beach slope. Instead the trend seems to be towards a relationship of the form

$$L_{zwm} \approx 0.05\ (H_{orms}L_o)^{0.5} \quad \text{for } \tan\beta_F \gtrsim 0.10 \qquad (11)$$

(see Figure 7). That is, L_{zwm} seems to be independent of the beach slope for the flatter beaches.

Table 1. *Summary of runup data.*

Location	Date	Time (EST)	H_{orms} [m]	T_s [s]	$\tan\beta_F$	C_1	r	$P\{z_s\}$	$c_1/\tan\beta F$	$-c_1c_2$
Brunswick	1/12-88	1040	0.53	7.0	0.043	0.038	0.999	0.33	0.88	−0.017
	22/12-88	1622	1.13	8.1	0.029	0.049	0.990	0.06	1.69	−0.026
	22/12-88	1702	1.13	8.3	0.029	0.054	0.988	0.19	1.86	−0.032
	22/12-88	1808	1.07	8.4	0.029	0.048	0.966	0.27	1.66	−0.032
	21/3-89	1635	1.20	11.5	0.090	0.031	0.987	0.38	0.34	0.009
	31/3-89	1515	1.91	8.0	0.080	0.044	0.993	0.37	0.55	−0.015
	22/8-89	1345	1.30	10.5	0.043	0.066	0.995	0.27	1.53	−0.038
	22/8-89	1515	1.25	10.2	0.043	0.038	1.000	0.04	0.88	−0.005
Dee Why	13/7-89	1010	2.92	11.3	0.113	0.042	0.999		0.37	0.010
	13/7-89	1050	2.95	11.4	0.113	0.043	0.996		0.38	0.010
	26/7-89	1045	2.58	8.5	0.118	0.059	0.984	0.37	0.50	−0.016
	26/7-89	1145	2.17	7.6	0.118	0.085	0.993	0.43	0.72	−0.033
	9/10-90	1045	1.12	8.0	0.188	0.127	0.986	0.51	0.68	−0.036
	9/10-90	1215	1.21	8.6	0.185	0.099	0.980	0.44	0.54	−0.029
	9/10-90	1342	1.14	8.5	0.174	0.080	0.992	0.51	0.46	0.002
Ocean Beach	24/7-89	1218	0.78	7.1	0.076	0.071	0.998		0.93	−0.026
*	24/7-89	1442	0.74	7.8	0.076	0.033	0.995		0.43	0.005
Palm Beach	18/4-89	1612	0.62	8.3	0.189	0.118	0.992	0.78	0.62	−0.018
	19/4-89	743	0.98	7.9	0.162	0.102	0.999	0.91	0.63	−0.003
	6/6-90	1415	0.96	6.8	0.068	0.067	0.988	0.24	0.99	−0.019
	6/6-90	1445	0.96	6.8	0.070	0.084	0.997	0.30	1.20	−0.036
	6/6-90	1515	0.96	6.4	0.077	0.106	0.967	0.40	1.38	−0.048
	2/8-90	1445	0.95	9.7	0.116	0.085	0.995	0.51	0.73	0.022
	3/8-90	1348	2.90	9.6	0.116	0.058	0.997	0.32	0.58	0.016
	3/8-90	1445	2.55	9.7	0.123	0.060	0.991	0.46	0.48	0.019
Pearl Beach	30/6-89	1615	1.55	8.8	0.150	0.094	0.991	0.60	0.63	−0.012
*	30/6-89	1650	1.58	8.7	0.150	0.116	0.980	0.50	0.77	−0.016
	30/6-89	1713	1.58	8.8	0.150	0.082	0.997	0.51	0.55	0.021
Seven Mile	21/8-90	1645	1.07	7.5	0.026	0.057	0.979	0.07	2.18	−0.048
Beach	22/8-90	1015	1.16	7.0	0.026	0.054	0.979	0.10	2.08	−0.044
	22/8-90	1245	1.10	7.4	0.026	0.041	0.971	0.01	1.58	−0.045
	28/9-90	1040	0.84	8.7	0.040	0.058	0.960	0.28	1.45	−0.055
	28/9-90	1200	0.80	8.2	0.041	0.059	0.995	0.30	1.44	−0.038
	28/9-90	1330	0.85	8.3	0.043	0.080	0.996	0.31	1.86	−0.051
	13/10-90	0704	3.76	11.1	0.037	0.041	0.995	0.07	1.11	−0.022
	13/10-90	1007	3.29	10.5	0.034	0.039	0.990	0.03	1.15	−0.044
	13/10-90	1342	2.78	9.8	0.041	0.052	0.992	0.17	1.27	−0.027

C_1 is related to the best-fit-distribution-scale by $L_{zwm} = C_1 (H_{orms} L_o)^{0.5}$

The relative vertical offset for the Rayleigh distribution is given by: $(z_{100} - SLOL)/(H_0L_0)^{0.5} = -c_1c_2$

*: Data from Turner (1989)

The Base Level of the Rayleigh Distribution

From the field data of the present study it seems that the base level, z_{100} of the best fit Rayleigh distribution *i.e.* the highest elevation which is transgressed by 100% of the waves is not significantly different from the still water level on steep beaches; the scatter is however very considerable, see Figure 8. For flatter beaches on the other hand, there is a definite trend which indicates that

$$z_{100} < SWL \qquad \text{for } \tan\beta_F \gtrsim 0.10 \qquad (12)$$

This corresponds to the fact that on these flat beaches, many waves transform into bores seaward of the still water line (D = 0) and that these bores tend to coalesce by overtaking one another. This results in fewer and fewer bore fronts closer towards the shoreline, and in general this will result in less than 100% of the waves reaching the still water line.

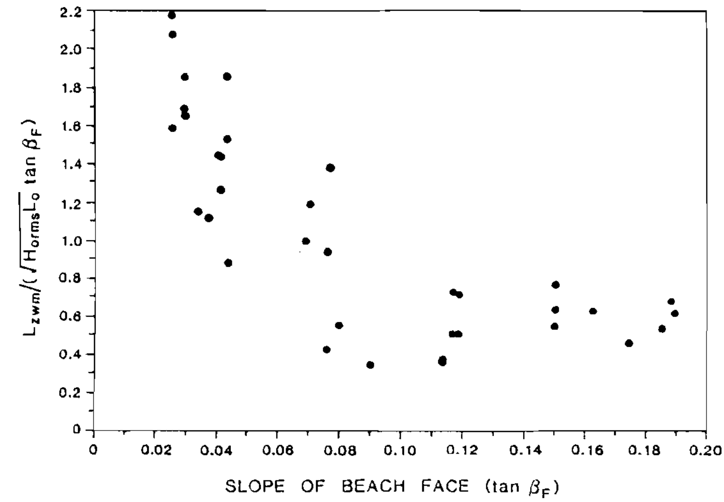

Figure 6. For steep beaches ($\tan\beta_F \gtrsim 0.10$) the scale of the runup distribution is well predicted by Hunt's Formula in the form equation (9).

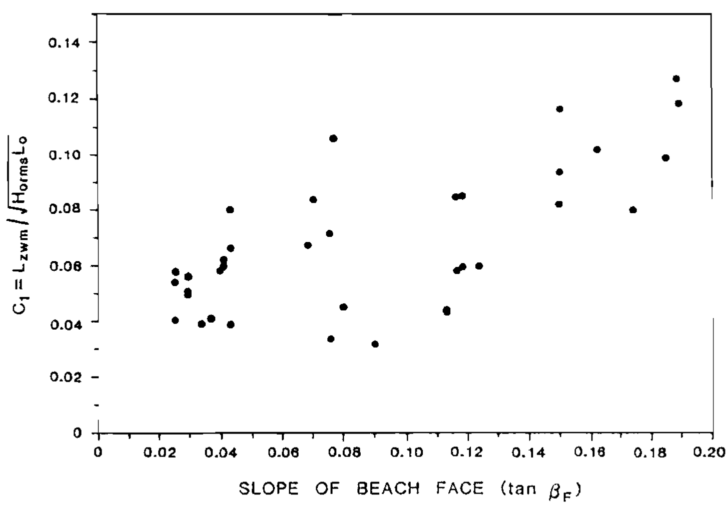

Figure 7. For flat beaches the data indicates that the vertical scale L_{zwm} of the runup distribution is independent of the beach slope.

The Shoreline's Position in the Runup Distribution

One step towards achieving an integrated picture of wave setup, wave runup and coastal watertable dynamics is to determine the position of the shoreline in the runup distribution, *i.e.*, what fraction of the waves are expected to transgress the shoreline on a given beach. One example involving a steep beach of coarse sand

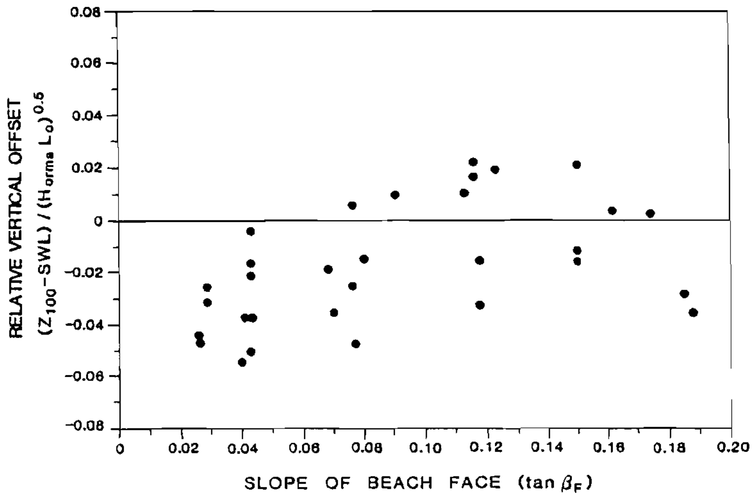

Figure 8. For the flatter beaches z_{100} is significantly below the still water level, while for the steeper beaches the deviation is not significant.

(Palm Beach) was shown in Figure 1. Steep beaches like Palm Beach drain rather efficiently and hence the Mean Water Surface will establish itself at a fairly low position relative to the runup/infiltration distribution, with most of the waves transgressing the shoreline.

On flat beaches of fine sand from which the water infiltrated from runup will drain very slowly, the MWS will intersect the beach close to the runup limit as reflected by the values of $P\{z_s\}$ in Table 1. $P\{z_s\}$ is short for $P\{z_{wm} > z_s\}$ and hence denotes the probability that a given wave will transgress the shoreline or the fraction of the waves that transgressed the shoreline in a given record.

$P\{z_s\}$ is a function of the relative tidal range R_{tide}/H_{rms} and the tidal phase as well as of the beach slope and permeability. Still, the data in Table 1, which correspond to mixed tidal phases show a clear relationship between the relative shoreline elevation and the beach slope (see Figure 9).

Distribution Scaling Without Survey Data

As discussed earlier the problem of defining the beach slope is not trivial on natural beaches. For very flat dissipative beach types, the problem is not too serious because changes in slope between the beach face and the surf zone are not large. For steeper beaches, however, beach face slope may be vastly different from the overall surf zone slope, and these beaches may or may not have surf zone bars.

The above mentioned problem and the fact that beach surveys are often not available has led many researchers to suggest the use of some type of parameter which describes beach morphology in terms of wave and sediment parameters alone (*e.g.* HOLMAN, 1986; NIELSEN, 1988). The use of the parameter

$$\Omega = H/w_sT \qquad (13)$$

where w_s is the sediment settling velocity, was suggested by NIELSEN (1988) as a likely means to get around the slope definition problem. The use of a parameter like this has, however, its own associated problems relating to the choice of representative values of H, w_s and T.

WRIGHT and SHORT (1984) showed that several aspects of beach morphology are well correlated with Ω when wave characteristics at breaking are used. Often however, accurate wave breaker characteristics are not available and in any case the choice of the appropriate time period for averaging the wave characteristics is not known. The extent to which beach morphology on any one particular day is influ-

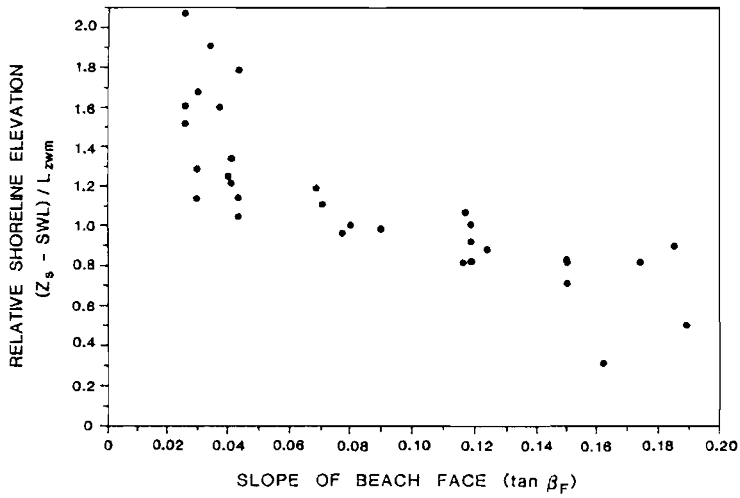

Figure 9. The elevation of the shoreline relative to the runup distribution is a decreasing function of the beach face slope because steeper beaches generally drain more efficiently than flat beaches.

enced by the previous days, weeks or even months of wave history is unknown. In addition sediment characteristics show significant variation between sub-environments within a beach system, thus the choice of the appropriate sand size is also subject to some uncertainty.

Figure 10 shows the relationship between the vertical scale of the runup distribution and Ω using offshore wave characteristics on the day of data collection, and mean swash zone sediment settling velocity, which given the discussion above, is only likely to provide an indication of the potential of Ω for describing runup. Interestingly however, even using deep water

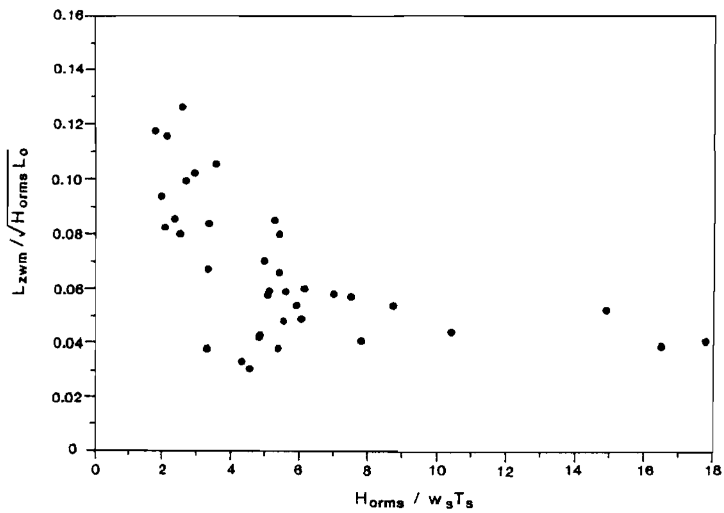

Figure 10. Vertical scale of the runup distribution *vs* Ω calculated using deep water wave parameters.

wave characteristics, and not considering the antecedent wave conditions, the data still show a demarcation between reflective and dissipative beaches. For values of Ω greater than about 6 the vertical scale of the runup distribution is independent of Ω. Hence, the transition between the two regimes where L_{zwm} is described by the formulae (9) and (11) respectively may alternatively be given by $\Omega \approx 6$. This value corresponds to the one suggested by Wright and Short (1984) as separating dissipative beaches from intermediate ones.

COMPARISON WITH PREVIOUS WORK

The runup distributions obtained in the present study agree well with some of the previous data while others differ in ways that are difficult to explain. Comparisons will have to be made under the assumption of the Rayleigh Distribution so that the different measured quantities can be compared. Under the assumption of the Rayleigh Distribution the following relations exist

$$z_{wmrms} = SWL + L_{zwm} \quad (14)$$

$$z_{wms} = SWL + 1.42\ L_{zwm} \quad (15)$$

$$z_{wm50} = SWL + 0.83\ L_{zwm} \quad (16)$$

$$\bar{z}_{wm} = SWL + 0.89\ L_{zwm} \quad (17)$$

$$z_{wm2} = SWL + 1.98\ L_{zwm} \quad (18)$$

$$z_{wm1} = SWL + 2.15\ L_{zwm} \quad (19)$$

where z_{wms} is the significant value of z_{wm} *i.e.* the average of the largest ⅓ of the observed values, z_{wm50} is transgressed by 50% of the waves, $\bar{z}_{wm}$ is the average level reached by the waves, z_{wm2} is the level transgressed by 2% of the waves and Z_{wm1} is the level transgressed by only 1% of the waves assuming $z_{100} = SWL$.

HOLMAN and SALLENGER (1985), monitored the motion of the waterline on the beach at the Coastal Engineering Research Centre's beach facility at Duck, North Carolina. The typical profile shape of this beach is somewhat similar to that at Dee Why Beach with an offshore bar and a beach face slope of roughly 0.10. The time series of the waterline position $\{x_w(t), z_w(t)\}$ were obtained with downlooking super-8 movie cameras and various statistics were derived. For example Holman (1986) gives the following best fit linear relationship between z_{wm2} and the significant wave parameters measured by a waverider in 20 m waterdepth.

$$z_{wm2} = 0.78\ H_s\xi_s + 0.20\ H_s \quad (20)$$

Alternatively a visual interpretation of the data from Holman's Figure 6c (Figure 11) gives

$$z_{wm2} \approx 0.90\ H_s\xi_s \approx 1.07\ (H_{rms}L_o)^{0.5} \tan\beta_F \quad (21)$$

which can be used for a direct comparison with equation (9). Through equation (18) it corresponds to

$$L_{zwm} \approx 0.54\ (H_{rms}L_o)^{0.5} \tan\beta_F \quad (22)$$

which is in good agreement with the data from the present study with beach face slopes around 0.10, *cf* Figure 5.

CONCLUSION

Previous studies have indicated the usefulness of the surf similarity parameter for the scaling of many nearshore processes including runup on coastal structures (*e.g.* BATTJES, 1971). Experiments on natural beaches have since confirmed this under a range of wave conditions (*e.g.* GUZA and THORNTON, 1981; HOLMAN and SALLENGER, 1985; HOLMAN, 1986). While the previous studies have each considered runup for various wave conditions on a single beach the present study presents data from a wide range of natural beach types.

The data indicate proportionality between the best-fit vertical scale L_{zwm} of the runup distribution and beach face slope for the steeper beaches:

$$L_{zwm} \approx 0.6\ (H_{orms}L_o)^{0.5} \tan\beta_F \quad \text{for } \tan\beta \gtrsim 0.10 \quad (9)$$

This is in qualitative agreement with Hunt's formula for runup, of regular waves on steep slopes (4). For the flatter beaches however, the slope becomes largely unimportant and a relation of the form

$$L_{zwm} \approx 0.05\ (H_{orms}L_o)^{0.5} \quad \text{for } \tan\beta_F \lesssim 0.10 \quad (11)$$

applies. Thus, for dissipative beaches the vertical scale of the runup distribution seems to scale directly with $(H_oL_o)^{0.5}$.

The precise position of demarcation in the data between the two regimes where the different types of formulae (9) and (11) are valid is open to interpretation, but a value of $\tan\beta_F = 0.1$ is suggested on the basis of the presently available data. Alternatively the distinction

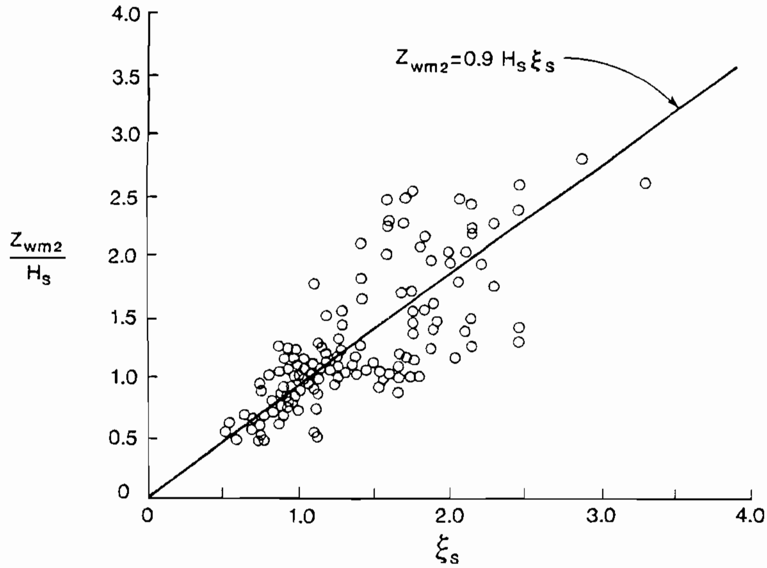

Figure 11. Data for extreme (2% exceedence) runup height as function of the Iribarren number. Data from Holman (1986).

may be made in terms of $\Omega = H/w_sT$ where the steep-beach-behaviour described by (9) occurs for $\Omega < 6$, while the flat-beach-behaviour prevails for $\Omega > 6$.

The second parameter, z_{100} of the best-fit Rayleigh distribution is not significantly different from the still water level for the steep beaches, but it is clearly lower for the flat beaches. The latter is mainly due to the coalescence of bores within the surf zone on these beaches.

The position of the shoreline relative to the runup distribution depends on the ability of the beach to drain between individual waves. In simple terms this means that the relative elevation of the shoreline is a decreasing function of $\tan\beta_F$ or an increasing function of Ω.

ACKNOWLEDGMENTS

The present study was supported by the Public Works Department of New South Wales. The authors wish to thank the many members of the department who contributed to the study, in particular Greg Davis, Tim Ruge, Rolyn Sario and Ralph Joergensen for much help with data collection and analysis, and also Krystyna Starmach for the drafting. Thanks also to Dr. Michael Hughes for comments on the manuscript.

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□ RÉSUMÉ □

Les distributions du jet de rive ont été mesurées sur un large spectre de plages de sable situées sur les côtes des New South Wales (Australie). La distribution de Raleigh est le modèle statistique raisonnable du niveau maximum atteint par les vagues individualles. L'echelle verticale du meilleur ajustement de la distribution est proportionnel au moment de la hauteur des vagues, au paramètre de similarité du déferlement pour les plages les plus pentues, ce, conformément à la formule de Hunt du jet de rive de vagues régulières sur des structures. Toutefois, pour des plages plates, l'échelle verticale de la distribution est indépendant de la pente. Le niveau de base du meilleur ajustment de la distribution (i.e. le plus haut niveau dépassé par toutes les crêtes de vagues qui arrivent) est impossible à distinguer du niveau de repos sur toutes les plages pentues, mais significativement bas sur les plages plates. La démarcation entre plages pentues et plages plates est une pente d'environ 0, 10, Le niveau du rivage relatif à la distribution du jet de rive est une fonction décroissante de la pente de la plage.—*Catherine Bousquet-Bressolier, Laboratoire de Géomorphologie EPHE, Montrouge, France.*

□ ZUSAMMENFASSUNG □

Die Verteilung der auflaufenden Wellen wurde an einer Vielzahl verschiedenartiger Sandstrände in Neusüdwales, Australien, gemessen. Die Werte zeigen, daß die Rayleigh-Verteilung ein brauchbares statistisches Modell liefert für die maximale Höhe, die von einzelnen Wellen erreicht wird. Der Vertikalmaßstab der am besten passenden Verteilung ist proportional zur Wellenhöhe multipliziert mit dem Parameter für die Brandung bezogen auf steilere Strände. Das stimmt mit Hunts Formel, die das Auflaufen gleichmäßiger Wellen auf Strukturen beschreibt, überein. Dagegen ist bei flachen Stränden der Vertikalmaßstab der Verteilung unabhängig von der Strandböschung. Das Basisniveau für die am besten passende Verteilung (d.h., das höchste Niveau, das von allen einlaufenden Wellenkämmen überschritten wird) ist an steilen Stränden nicht vom Stillwasserniveau zu unterscheiden; an flachen Stränden ist es dagegen signifikant tiefer. Bei diesen Betrachtungen liegt die Grenze zwischen "steilen" und "flachen" Stränden bei einem Strandgefälle von ungefähr 0, 10. Das Niveau der Strandlinie ist in bezug auf die Verteilung der auflaufenden Wellen eine abnehmende Funktion des Strandgefälles.—*Helmut Brückner, Geographisches Institut, Universität Düsseldorf, Universitätsstr. 1, D-4000 Düsseldorf 1, Germany.*

□ RESUMEN □

Se ha medido la distribución del run-up en un amplio espectro de playas en la costa de Nueva Gales del sur, Australia. Los datos indican que la distribución de Rayleigh es un modelo estadístico razonable para los niveles máximos alcanzados por las olas individuales. La escala vertical de la distribución de mejor ajuste es proporcional a H (altura de ola) veces el número de Iribarren para la playa más pendiente en concordancia con la fórmula de Hunt para run-up de olas regulares sobre estructuras. Para planas, sin embargo, la escala vertical de la distribución es independiente de la pendiente de la playa. El nivel de base para la distribución de mejor ajuste (por ejemplo, el maximo nivel alcanzado por todas las crestas de las olas incidentes) no difiere significativamente del nivel medio en playas muy pendientes pero es significativamente menor en playas tendidas. El límite entre playas tendidas y pendientes está en una pendiente del talud de playa de aproximadamente .10. El nivel de la línea de costa relativo a la distribución del run-up es una función decreciente con la pendiente de la playa.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*