

## CHAPTER 65

### Kinematics of Breaking Waves in Coastal Regions

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Waves breaking on various slopes in a wave flume are examined. Plunging and spilling breakers are considered. The parametric results show the consistency of the measurement and the independence of scale. A method is given for predicting the maximum breaking height for a wave of known period in a known depth. The velocity is measured to the crest of the wave and comparisons with numerical and analytical solutions demonstrate the shortcomings of many of the established methods of predicting wave kinematics.

#### Introduction

Breaking waves are of significant importance in the design and understanding of many aspects of Coastal Engineering such as breakwaters, bed movement and inshore construction. Yet the kinematics of these waves are not fully understood despite considerable advanced theoretical and numerical work (e.g. New et. al., 1985). Mathematical models are limited in several ways at present. For example, although deep and shallow waves may be modelled it has not been possible to include changes in bed topography such as linear slopes. Also, the flow field becomes complex when the plunging jet of a breaker hits the forward face making the spilling or surging breakers difficult to model.

Experimentally, the measurement of kinematics is complicated by the two-phase situation which exists above the still water level precluding the use of many standard velocity probes. For this reason mathematical models have usually been inadequately compared with surface profiles.

Due to the difficulty of obtaining breaking wave kinematics, designers have tended to rely on the tried and tested industry standards such as Stokes and Cnoidal theory or Dean's stream function. Recently, higher-order versions of Dean have been available, applicable to larger waves (Chaplin, 1980). All of these assume two dimensional, regular non-breaking waves and necessarily provide limited

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descriptions.

Furthermore none of the above methods can give a reliable limiting wave height and the question of whether the 'design wave' might be breaking is dependent on data gathered from elsewhere on height over depth ratios (Griffiths et al, 1987). For this reason several companies have commissioned site-specific studies at the Edinburgh

Fluid Dynamics Unit to discover if the design wave was a breaker and if so what its kinematics were (Birkinshaw et. al., 1988).

This paper will look at spilling and plunging breakers on beds of various slopes in terms of their parameterisation and internal kinematics. A method of using these results will then be proposed.

#### Experimental method

Regular waves are generated in a narrow tank by a computer-controlled absorbing wavemaker. The wavemaker is in 'deep' water (0.9 m) and the waves are run up a slope of variable degree. For gentle slopes and flat beds an initial steep slope is used (fig. 1).

The velocity measuring technique is Laser Doppler Anemometry. The non-intrusive system records the frequency of variation of light scattering intensity as minute seeding particles pass through the crossing volume of two laser beams. The application of this technique to breakers may be found in Easson & Greated (1984). The method of signal analysis allows measurements up to the crest of the breaking wave which is not common in most systems but will be shown to be of great importance.

Wavelength, height, and velocity were measured using still photography and a video-camera. (figs. 2, 3).

#### Results

##### (a) Parametric

The wave parameters measured were deep water height ( $H_0$ ), breaking height ( $H_b$ ), breaking depth ( $d_b$ ), maximum crest elevation ( $H_{1b}$ ) and trough depression ( $H_{2b}$ ) wavelength at breaking ( $L_b$ ) and velocity at breaking ( $C_b$ ) (see fig. 4). The breaking point is when the crest first becomes vertical. For ease of presentation and application of the results the deep water steepness ( $S_0 = H_0/l_0$ ) has been used as the reference axis. This has been shown to be useful and valid over the range  $0.015 < S_0 < 0.115$  in a previous publication (Griffiths et al, 1987), as would be expected since Froude scaling applies here. Furthermore no correction factors are required in applying these results to full scale waves.

The range of slopes considered is 1:15, 1:30, 1:50 and flat bed. Most of the waves produced spilling breakers but the longest waves on the 1:30 slope (small  $S_0$ ) and most of the waves on the 1:15 slope became plunging breakers.

The first plot (fig. 5) shows the depth at which the waves broke. All length scales have been non-dimensionalised by the deep water wavelength so  $d_b' = d_b/gT^2$ . This shows that the depth of breaking is independent of slope or period and is purely a function of deep water steepness.

The limits are as expected with the graph passing through zero (no height, no breaking) and tending towards the deep water breaking limit ( $S_0 \approx 0.14$ ) as the breaking depth increases. Figure 6 shows the breaking wave height which is also independent of slope or period and tend towards a deepwater limit of 0.022 at  $S_0 = 0.142$ . This has been compared with the regular criteria of  $H_b' = 0.027$  and the irregular limit of  $H_0' = 0.020$ . (Ochi and Tsai, 1983).

It is possible, using figs 5 and 6, to read off the breaking wave height given the design parameters of depth and period. For example, a 12.5s wave in a depth of 25 m (typical North Sea) gives  $d' = d/gT^2 = 0.016$ . From fig. 5,  $S_0 = 6.0$  which from fig. 6 gives  $H' = 0.011$ . Therefore the breaking wave limit height is  $H_b = gT^2 \times H' = 16.8$  m. If hindcasting has predicted a height greater than this then the wave will be breaking.

Designers have often used the criterion  $H_b/d_b > 0.78$  to determine whether a wave is breaking. This is derived from shallow water solitary wave theory (Munk, 1949) and should not be used for intermediate depths. Figure 7 shows  $H_b/d_b$  against  $S_0$  for our results. Previously (Griffiths et al, 1987) the 1:30 results were shown to match the results of other investigators on this slope; they also extended the range to deeper water. Weggel (1982) proposed an empirical upper limit based on the 1:30 slope results. Several significant points may be drawn from this figure. Firstly, the flat bed results tend to the solitary wave limit at small  $S_0$  and the Weggel line is overly conservative. Secondly, the  $H/d$  ratio is slope dependent - a fact which is not apparent from figures 5 and 6. Finally, the Weggel line cannot be applied to slopes greater than 1:30 as the plunging breakers here exceed the  $H_b/d_b$  ratio predicted.

Svendsen and Buhr Hansen (1976) plot wavelength over depth at breaking as a function of deep water steepness. The results here (fig. 8) confirm the slope of Svendsen's empirical mean value line and extend the range of results towards the deep water limit.

#### (b) Kinematic results

Velocities were measured under the crest of the wave at a range of elevations from the bed to the crest peak at the instant of breaking. Figure 9 shows the velocity variation from bed to crest of five wave frequencies breaking at a particular depth (185 mm) on a 1:50 slope. The most important general characteristic is the large increase in velocity in the crest where the graph steepens considerably. Thus although the near bed velocities are as expected the crest velocities differ considerably from non-breaking waves. The curvature of the graph is greatest for the short waves which have lower velocities below SWL. The group of points to the right of the graph are the five celerities associated with the frequencies studied, plotted at the maximum elevation of the crest. In each case the velocity curve tends towards the celerity at crest indicating that this is the maximum velocity (although it may only pertain to a very small fraction of the crest volume) and that the condition  $v = c$  does indeed represent a useful criterion for wave breaking.

Figure 10 shows the velocity under the crest of a 1 Hz wave breaking at 185 mm depth for different slopes. There is no significant difference between the 1:50 and 1:30 results but higher velocities were measurable for the 1:15 slope due to the larger volume of water

travelling at velocities around  $c$  in the plunging jet. (c.f. figures 2 & 3). The plunging breaker was also slightly higher than the others.

Finally, the quality of these results has enabled a direct comparison with some of the established theories. This is only possible when crest values can be obtained. The lack of crest values invalidates the comparisons made by previous investigators as this is where the major differences between breakers and non-breakers arise. Figure 11 shows the velocity variation with elevation for one particular wave but the trends are typical over the full range of conditions investigated. The comparisons are with Linear, Stokes V and Deans V and IX. (We are grateful to Professor J. Chaplin for the comparison with Deans IX (Chaplin, 1980)). The measured velocities tend towards the indicated celerity/height point and the best fit curve has been drawn. The Stokes V has also been indicated by a full curve. Interestingly, the linear theory gives a better fit than Stokes in the crest. The two Deans solutions are better approximations with the ninth giving a significant improvement in the crest. However, even this falls 20% short of the maximum expected velocity. Note that all the theories tend to over-predict the velocity below SWL.

### Conclusions

By testing a range of frequencies, Froude scaling has been shown to apply to breaking waves. The parametric results have shown good agreement with those of other experimenters and have usefully extended the range of measurements. A method has been presented for the evaluation of limiting wave heights in the design of offshore structures using graphical procedures. The  $H/d$  ratio for breaking is slope dependent but is only significantly so for shallow/plunging breakers. Throughout the range measured the velocity in the crest tends to a maximum equal to the celerity at the highest point of the wave. The established theories tend to underestimate the crest velocity and overestimate the velocities below SWL.

It is important to remember, in the application of these results, that the two-dimensional, regular wave assumption has been made, as is the present industry practice. A project is currently under way, at Edinburgh University, using the instantaneous full-field anemometry technique known as Particle Image Velocimetry (PIV) (Gray & Greated, 1988) to measure the velocities under irregular breaking waves.

### Acknowledgements

Mr. Griffiths is a postgraduate student in receipt of a CASE studentship with B.P International. The authors would particularly like to acknowledge the help and access to industrial procedures afforded by B.P. This project is part of the managed Fluid Loading Programme of MTD Ltd. We are also grateful for the encouragement and interest shown by various members of that organisation.

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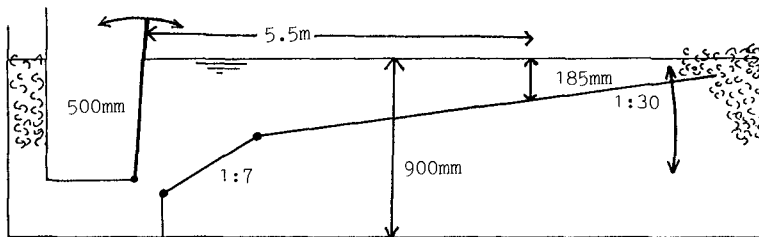


Fig. 1 - Typical beach dimensions

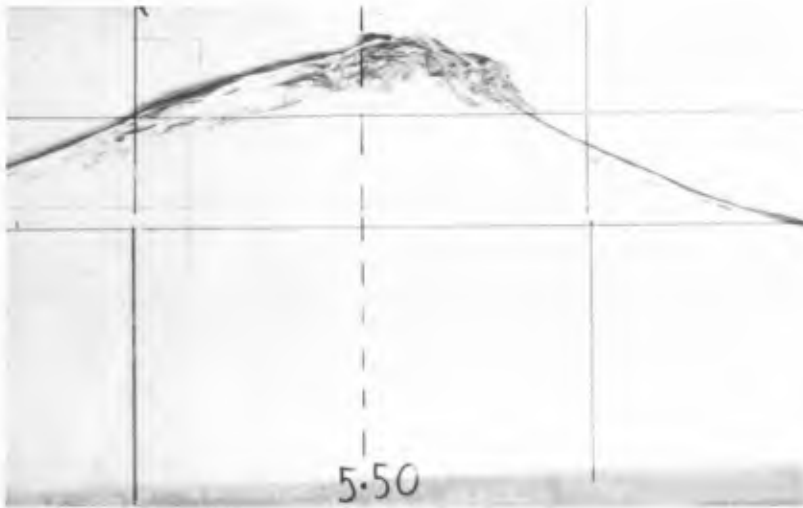


Fig. 2 - Depth induced spilling



Fig. 3 - Depth induced plunging

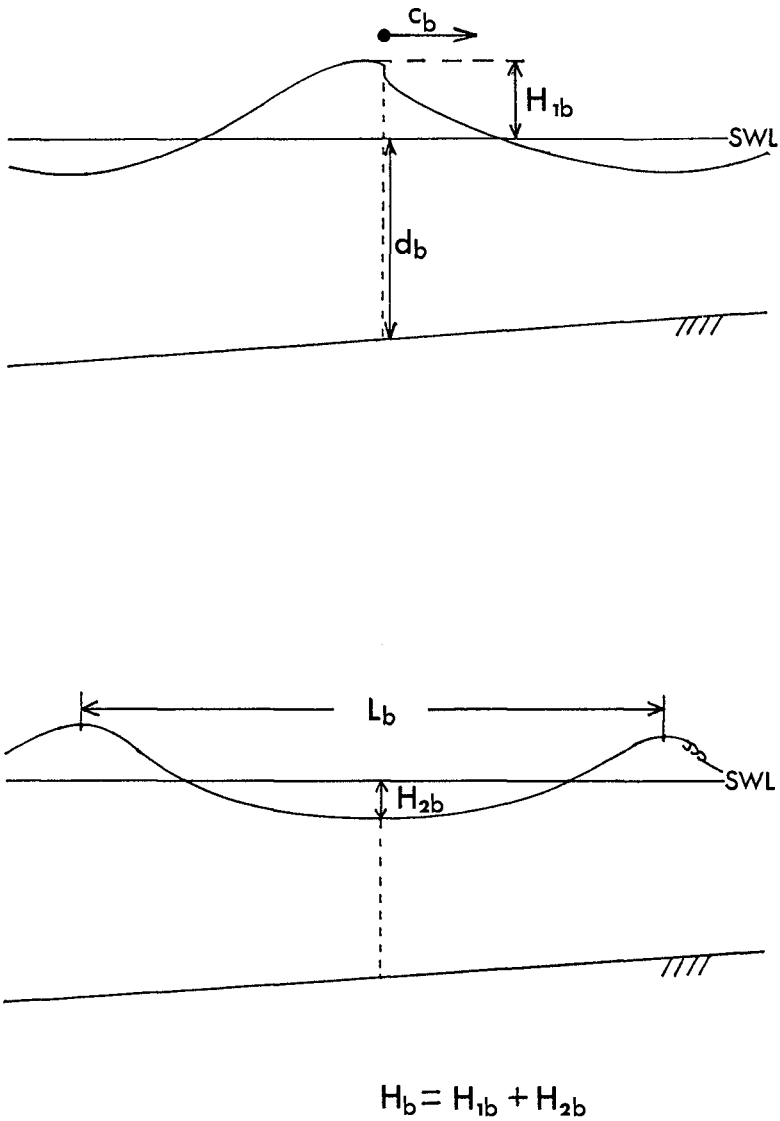


Fig. 4 - Definition of parameters at measuring point

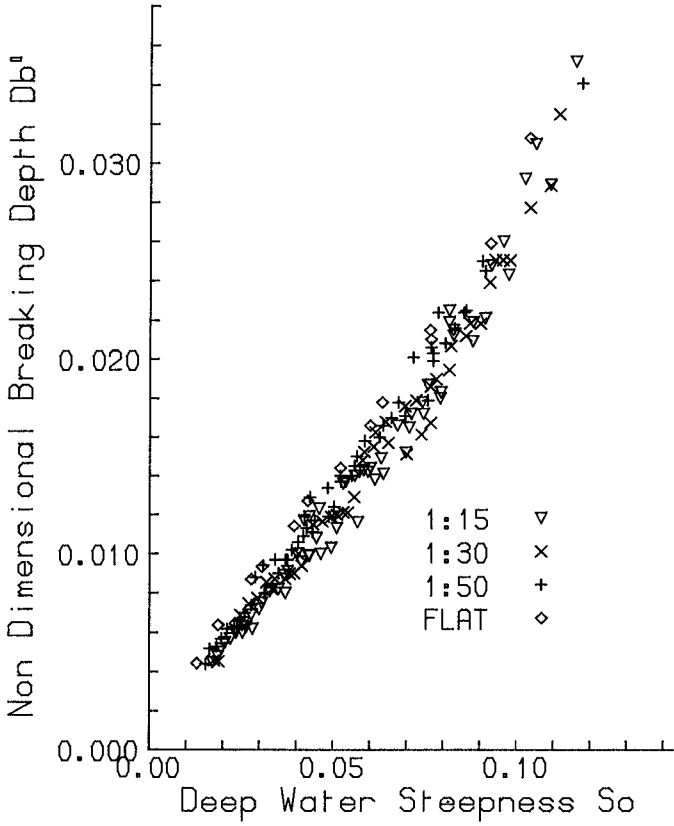


Fig. 5 -



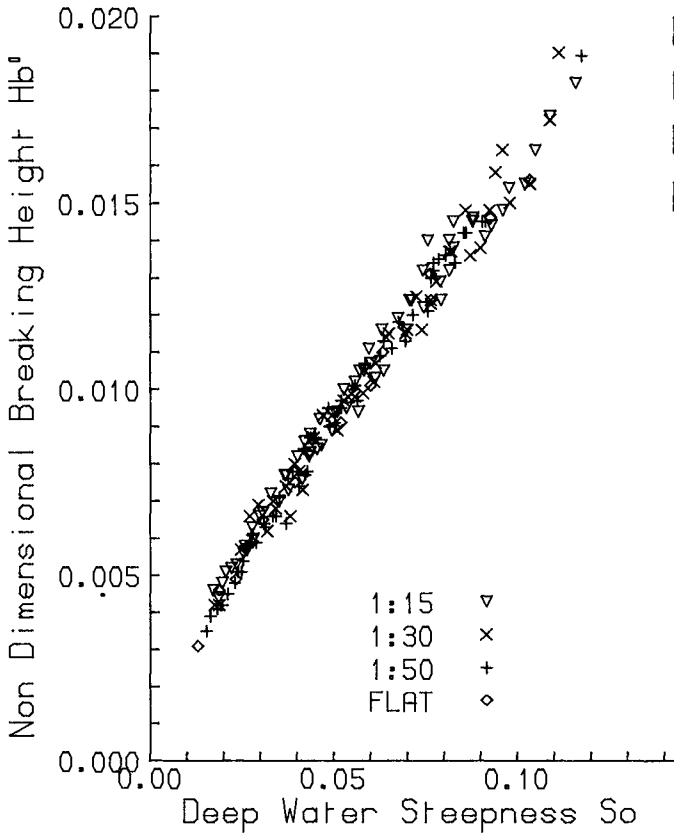


Fig. 6 -

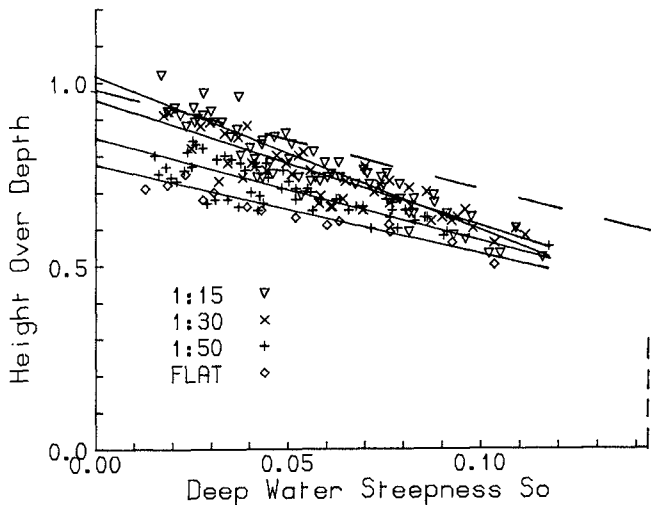


Fig. 7 -  $H/d$  at breaking. The four solid lines are best fits to the results from each slope (steepness increases with greater  $H/d$ ). The dashed line is Weggel's empirical line.

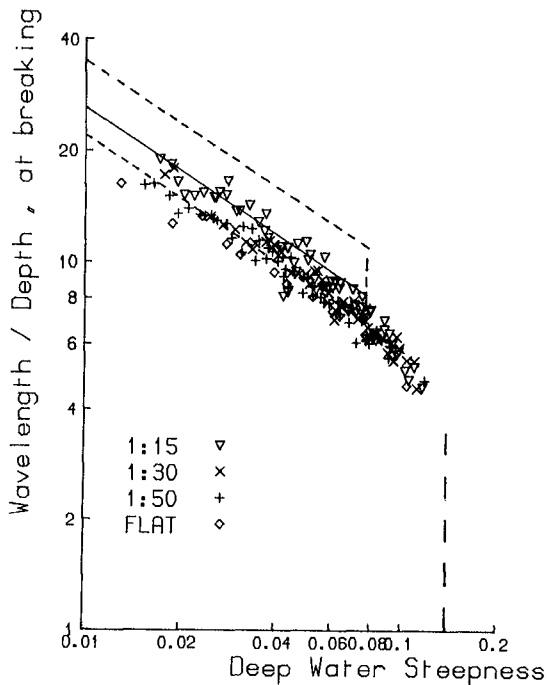


Fig. 8 - Comparison with Svendsen (boxed area indicates extent of Svendsen's scatter)

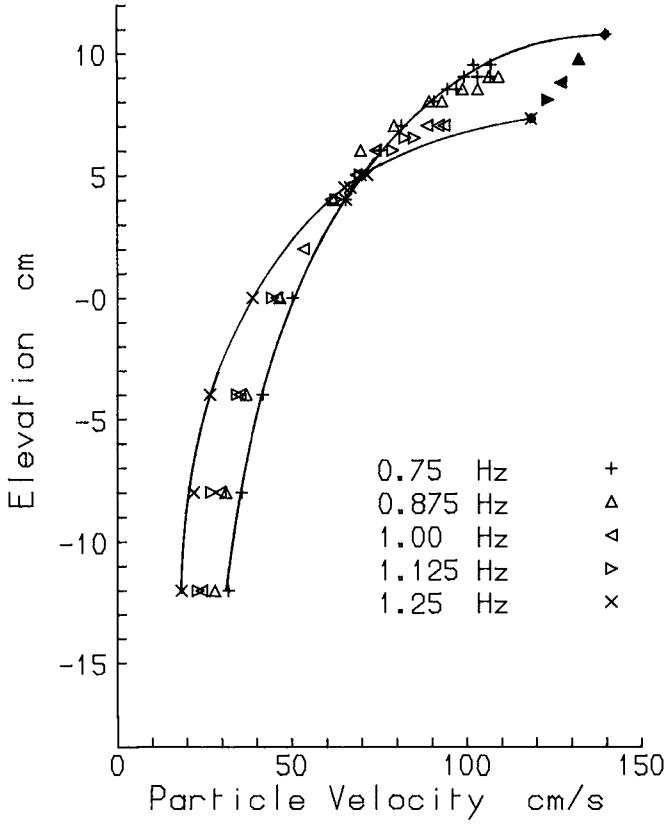


Fig. 9 - Particle velocity v. elevation. Dependence on frequency (1.50 slope)

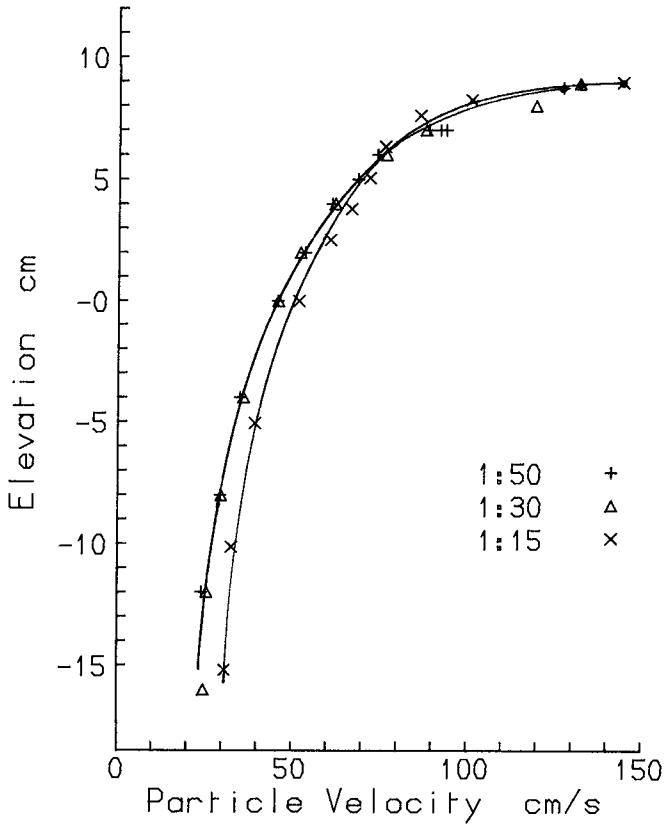


Fig. 10 - Particle velocity v. elevation. Dependence on slope. (1 Hz wave.)

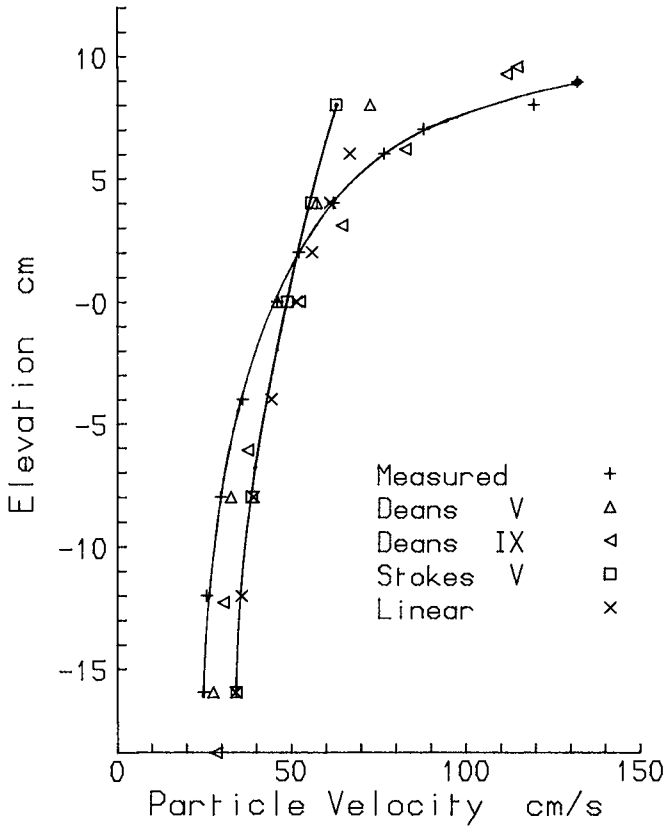


Fig. 11 - Particle velocity v. elevation. Comparison with theory (1 Hz, 1.30 slope.)