CHAPTER 43

WAVE RUN-UP ON A SIMULATED BEACH

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ABSTRACT

A set of experiments concerning wave run-up in the presence of an offshore bar is described. Results pertaining to the direct relationship between incident waves and run-up heights are presented. It is clear that in the majority of cases the offshore bar does reduce run-up heights. The experiments showed that under certain conditions very large run-up and run-down heights are produced. This is ascribed to a resonance effect between either the basin, formed between the bar and the beach, or the beach face and the incident waves.

INTRODUCTION

The run-up resulting from the arrival of a train of waves at a beach slope is an important design consideration in many coastal engineering problems. Wave run-up is the maximum vertical height, above the local mean water level, reached by a wave at the end of its travel across the beach.

In reaching the beach, waves pass through the breaking zone and the surf zone in each of which they experience highly non-linear transformations and undergo energy dissipation. Studies of the run-up produced by a bore (Meyer and Taylor, 1972) indicate the importance of frictional dissipation in determining run-up. Other important effects include the interactions between successive waves (by collisions) on the beach slope and the presence of an offshore bar which can cause breaking. The former is important when irregular wave trains are considered while the latter applies to periodic waves as well as to irregular waves. Both effects increase energy dissipation to an unknown extent.

Laboratory measurements of run-up made by van Oorschot and d'Angremond (1968), with mechanically generated waves, and by Webber and Bullock (1968), with wind generated waves, have provided data for conditions in which interactions between waves on the beach slope are an important factor. Battjes (1971) has presented an analytical model of this process but no comparison with data was attempted. Field measurements of run-up by

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Waddell (1973) and Sonu et al (1974) must reflect, in addition to the above interactions, the influence of many other factors including the offshore profile, the beach profile, the beach roughness and permeability and the characteristics of the incident waves.

The present study is primarily concerned with the effect of a beach profile which includes a bar. Such profiles are typical of the east coast of Florida. Tests were conducted in the laboratory using a profile modelled on that at Jupiter Island, Florida. Effects of the pronounced offshore bar were determined by measuring wave run-up with a variety of incident wave and water depth conditions.

EXPERIMENTAL APPARATUS AND PROCEDURE

The experiments were performed at the University of Florida in the Coastal and Oceanographic Engineering Laboratory air-sea facility, shown in Figure 1, which has been described by Shemdin (1969). Waves are generated by a plate hinged at the bottom and driven by a hydraulic piston. Sinusoidal waves with frequencies in the range 0.2 to 4.0 Hz can be produced with amplitudes up to 10 cm. By using prepared analogue tapes as input the wave generator can be driven so as to produce irregular waves of known spectral shape. There is provision for blowing air over the waves. This was not used in the present experiment.

A model (approximate scale 1:20) of the Jupiter Island beach profile as measured in November-December 1974 was placed at the beach end of the facility. Figures 2 and 3 show the beach profile and the model as constructed. For water depths over the bar of less than 30 cm (68 cm total depth) it was not possible with the wave generator hinged at the base, to generate waves of height comparable to the water depth over the bar. For subsequent tests with reduced water depths at the bar the profile was raised 23 cm and the forward slope of the offshore bar extended at the same slope until it again met the floor of the channel. At the minimum bar depth tested, 5 cm, the water depth in the channel was 66 cm in which waves of sufficient height could be easily generated. For tests with a plane beach slope the horizontal section and the bar were removed from the channel.

Capacitance wave height gauges made from Nyclad insulated wire were placed at the mid-point of the horizontal section 6.10 m "seaward" of the bar at station 2 and 18.29 m "seaward" of the bar at station 4. Most calibration curves were linear with the occasional one consisting of two straight lines meeting near the zero point. Hewlett Packard 7700B recorder bridge circuits conditioned the signals from the gauges. The bridge output, an analogue voltage signal, was taken directly to a Kinemetrics DDS 1103 (16 channel) Data Acquisition System set to digitize the signal at 10 samples/sec.

A 1.88 cm diameter spiral wound resistance wire wave-staff manufactured by Oceanographic Services was installed parallel to and 6.3 mm from the beach face (see Figure 4). The associated electronics gave an analogue voltage output which was sampled by the data acquisition system at 10 samples/sec, essentially simultaneously with the wave height records. The gauge was calibrated by filling the facility above the level of the

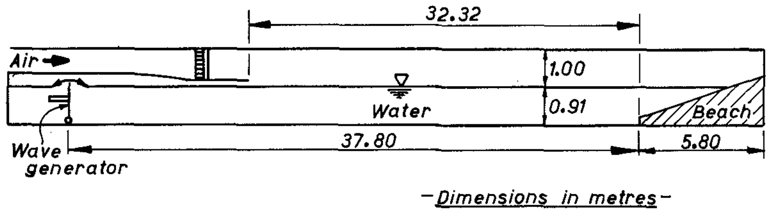

Fig.1 :- LONGITUDINAL SECTION OF AIR-SEA FACILITY

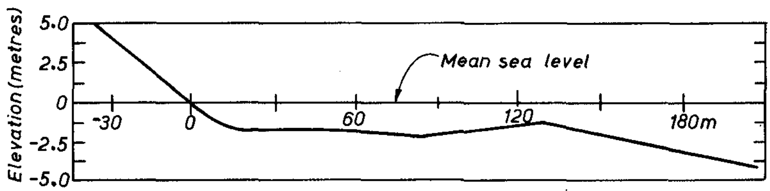

Fig.2 :- TYPICAL BEACH PROFILE AT JUPITER ISLAND

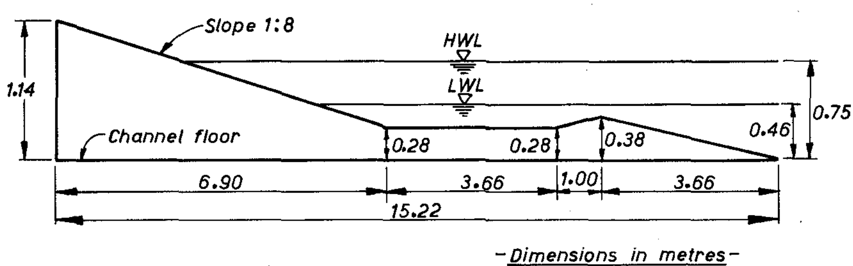

Fig. 3 : BEACH PROFILE MODEL

highest expected run-up and then lowering the water level slowly. At selected points the water surface elevation and the resultant output voltage were noted. The calibration curves were closely approximated by two straight lines of similar slope and in a few instances were exactly linear.

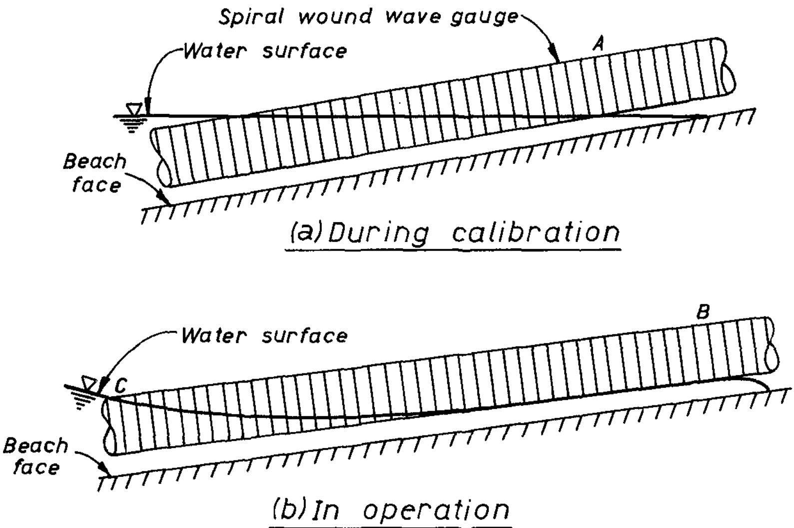

Fig.4:—SPIRAL WOUND WAVE GAUGE USED FOR MEASURING RUN-UP

A prepared analogue tape was used to provide an input signal for the wave generator. This produced waves having a Bretschneider spectrum and was used for all tests with irregular waves.

At each of eight water depths at the bar a series of tests was performed. Firstly irregular waves having a Bretschneider spectrum were generated and the run-up recorded. Five such runs with different significant wave heights were carried out. Then sinusoidal waves with a frequency of 0.7 Hz, corresponding to the frequency of the peak of the spectrum of the irregular waves, and various wave heights were examined. Sinusoidal waves of 0.3 Hz were also investigated as the peak of the run-up spectrum occurred at 0.3 Hz.

With the bar removed the same series of tests was performed on a plane beach with a water depth of 41 cm in the channel.

The data recorded during each run was the water depth at the bar, the output from the run-up gauge and the three wave height gauges and the RMS voltage supplied to the wave generator. The last being a measure of input wave energy. The digitised records as recorded on tape were processed at the NERDC computing center.

In all, 109 runs were performed. The output from the computer for all these runs is available in the Coastal Engineering Department. The calibrated records have been recorded on a master tape deposited at the NERDC.

RESULTS AND ANALYSIS

Some general observations and impressions are given first. These are followed by the numerical results.

General Observations

Irregular waves cause run-up patterns on a plane slope which differ markedly from those created by regular waves. In these experiments the dominant frequency of run-up (approximately 0.3 Hz) was noticeably less than that of the incident waves (0.7 Hz) and the run-up distribution appeared wider than the wave height distribution. Spectral widths of the run-up ranged from 0.6 to 0.7 compared to 0.42 to 0.49 for the incident waves. Both effects (lower dominant frequency and wider spectrum) result from collision and overtaking on the beach slope. These mechanisms are the significant ones in determining the run-up distribution.

Webber and Bullock (1968) noted that it is often impossible to attribute a particular run-up crest to any individual wave. This was certainly true in the present experiments being most noticeable in the presence of a bar on which a significant number of the incident waves broke.

Most experiments showed a significant rundown which may be defined as the vertical distance below still water level to which the water's edge retreats. There were also negative run-up heights, maxima in the run-up record, which were as much as 2.0 cm below still water level. This would seem to be a result of seiching in the basin lowering the mean water level at the beach as a small wave reached the beach. Such seiching would be excited if the incoming wave has frequency components corresponding to the natural frequency of the basin. With sinusoidal waves of 0.7 Hz both the run-up and the run-down were less than for sinusoidal waves of 0.3 Hz at much smaller incident wave heights. An example is given in Table 1. The high run-up shown for 0.3 Hz could result from the beach having a natural swash frequency of 0.3 Hz, but it is hard to see this producing the observed run-down. Present results do not allow seiching effects to be separated from resonance effects on the beach.

TABLE 1

RUN-UP AND RUN-DOWN FOR SINUSOIDAL WAVES

Bar Depth (cm)	Wave Frequency (Hz)	Incident Wave Height (cm)	Run-up (cm)	Run-down (cm)
15	0.7	11.0	6.1	-
15	0.3	4.8	11.4	4.9

Having more wave gauges in the basin would possibly allow these effects to be separated. Using the same beach slope with a basin of different geometry may shed light on relative importance of the seiching and the beach resonance.

For a given water depth over the bar the percentage of waves breaking on the bar increased with incident wave height. With sinusoidal waves, spilling from the top occurred when the incident wave height was approximately 60% of the bar water depth. On reaching 70% of the bar water depth all the waves were breaking at the bar crest. For further increase in wave height the break point moved "seaward" down the slope leading to the bar. Observations typical of those made with irregular waves are given in Table 2.

TABLE 2

BREAKING PERCENTAGE FOR IRREGULAR WAVES

Bar Depth (cm)	Significant Incident Wave Height (cm)	Percentage of Wave Breaking
25	10.4	0
	13.1	5
	16.2	20
	20.4	70
15	7.6	5
	11.5	20
	16.4	70
	20.4	>90

For a water depth at the bar of 5.0 cm the incident wave height seemed almost irrelevant for the run-up. Waves all broke on the seaward slope of the bar and spilled over into the basin. This created waves in the basin which in turn resulted in run-up. The waves were much more regular and much smaller than the incident waves; their properties were probably governed by a combination of the basin geometry and the impulse given to the water in the basin. This represents one end of the spectrum of possible effects caused by the presence of a bar. The other end is when the bar is absent or ineffective.

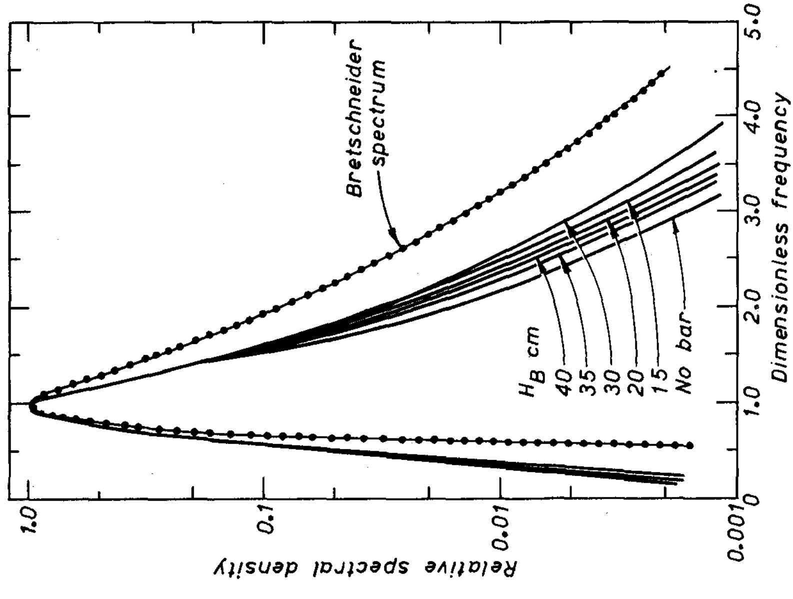

Fig.5:– INCIDENT WAVE SPECTRA AND BRETSCHNEIDER SPECTRUM

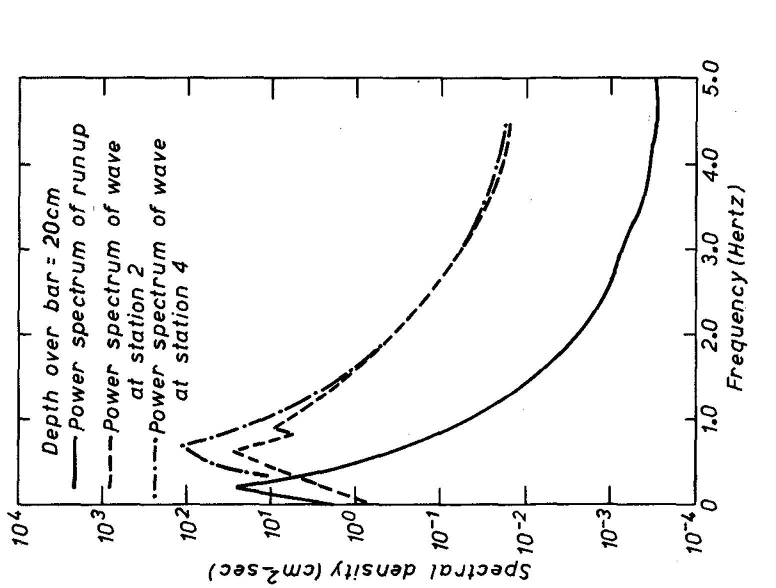

Fig.6:– SPECTRA OF RUN-UP, WAVES BETWEEN BAR AND BEACH (St.2) AND INCIDENT WAVES (St.4)

Numerical Results

Incident Wave Spectra: Smoothed incident wave spectra from all runs at a given bar water depth H_B were plotted in dimensionless form and averaged. Figure 5 shows there is little difference between the spectra at different water depths. However, the generated spectra contain more power at low frequencies and less power at higher frequencies than does the Bretschneider spectrum. The spectral width parameter, ε, as defined by Oorschot and d'Angremond (1968) ranged from 0.42 to 0.49 for the generated spectra.

Run-up Measurements: The run-up gauge was designed as a wave staff to be used in a vertical position. When placed on a 1:8 slope and being 1.88 cm in diameter a horizontal water surface intersected the staff over 15.0 cm of its length, see Figure 4a. By calibrating as described above it was assumed that the gauge would be shorted from the last wetted coil down to its lower end, i.e. from coil A in Figure 4a. Then during operating conditions, see Figure 4b, the level recorded would be that of coil B and as such a good measure of the run-up height. However, it appears that simply wetting the coils along the underside of the staff is not sufficient to short them out. The value recorded actually lay somewhere between B and C of Figure 4b where the water surrounds the staff in a way equivalent to that during calibration. The effect is worst when the run-up is highest. Such run-up has a very long thin tongue that extends up the slope and only the underside of the gauge is wet for perhaps 60.0 cm corresponding to a vertical height of 7.5 cm. The error in reading these highest run-ups may thus be 3 or 4 cm in 15 or 20 cm. For the majority of the run-ups, those without very long tongues, the error is of course much less.

This effect was first noticed when values of run-up height on a plane beach divided by incident wave height less than published values were being obtained. A check on the gauge was made in a number of experiments. The run-up height was measured by marking the maximum excursion on the beach face and later measuring its position relative to still water level. These values were later compared with those measured by the run-up gauge. For sinusoidal wave input this is a viable technique because the run-up does not vary significantly between waves. For irregular waves only the maximum could be recorded and an estimate made of the mean.

Such observations confirmed that high run-up values were being under estimated. In some cases this amounted to 25%. One cannot however reliably estimate the error introduced into the results because, particularly for the irregular waves, the shape of the run-up tongue will vary from run-up to run-up. The effect on the run-up spectrum may not be as serious since each run-up event would be recorded and the record would reach a peak at virtually the same time as the run-up peak. The effect is not simply to clip the top off each peak and thus introduce spurious frequency components.

Clearly a different type of gauge must be designed and built for any further tests. It must be such that it responds to point wetting. A step gauge made from a series of electrical contacts each of which records the presence or absence of water is recommended.

In spite of run-up measurement limitations as discussed above, it has been possible to obtain valuable results on run-up dynamics in the presence of a bar. Spectra of run-up, incident waves (at St. 2) and waves behind the bar (at St. 4) are shown in Figure 6. The spectrum behind the bar is lower than the incident wave spectrum as a result of bottom friction between the two gauges and of dissipation over the bar. The peak frequency of waves remains unchanged before and after the bar. The run-up spectrum, however, shows a distinct shift in the peak frequency to a lower value. Significant dissipation in the higher frequencies and amplification of the lower frequencies in the run-up records is evident. The coherency between the incident waves and run-up height is generally small.

Interesting results on run-up dynamics are also deduced from the equilibrium slope of the spectrum. The incident wave spectrum is shown in Figure 7 and has the (-5) slope expected for gravity waves. The corresponding run-up spectrum exhibits a (-4) slope in the equilibrium range as shown in Figure 8. Dimensional analysis based on the assumption that the dominant spectrum parameters are turbulence intensity, (cm^2/sec^2) and frequency, (Hz) yields a slope of (-4) in the equilibrium range. In contrast gravity and frequency yield a (-5) slope for gravity waves. The result of Figure 8 coupled with the fact that normally significant breaking occurs on the bar suggests that the dynamics of run-up are dominated by turbulence rather than by gravity.

The statistics of the run-up height also differ from those associated with the narrow band gravity wave spectrum. Figure 9 shows the run-up height distribution on probability paper and suggests that run-up can be reasonably described by a Gaussian distribution. This is in accord with the results of Webber and Bullock (1968). It is clear that despite the highly non-linear process affecting run-up, as deduced above, run-up remains a random process but with a different signature. The Gaussian run-up distribution is consistent with the broader band spectrum of Figure 8 compared to that of Figure 7.

Reduction of Run-up Due to Bar:

The direct effect of the bar is to reduce the energy in the wave train. A measure of this energy is the area under the power spectral density curve. The percentage reduction in this value as a function of water depth at the bar H_B is given in Figure 10. The reduction refers to that occurring between a wave gauge 18.29 m from the bar and the gauge in the basin. Some of the reduction is therefore due to viscous action as the waves move along the channel. It appears as though this may be about 25% because at H_B/H_S greater than 3.5, the effect of the bar can be expected to be small.

The effect of this reduction in energy can be seen in Figure 11. Here run-up height has been plotted as a function of incident wave height. The points were derived from the observations made with sinusoidal waves. The number beside each point is the ratio H_B/H_S. As the ratio reduces the points tend to fall further below the standard Beach Erosion Board curve.

Run-up divided by incident wave height as a function of incident wave steepness is shown in Figure 12, in which the points of Figure 11 have been replotted. The number beside each point is again the ratio H_B/H_S. Ignoring those points corresponding to a bar depth H_B of 5 cm (for reasons discussed under General Observations above) there is a tendency for high values of H_B/H_S to be towards the upper left and low

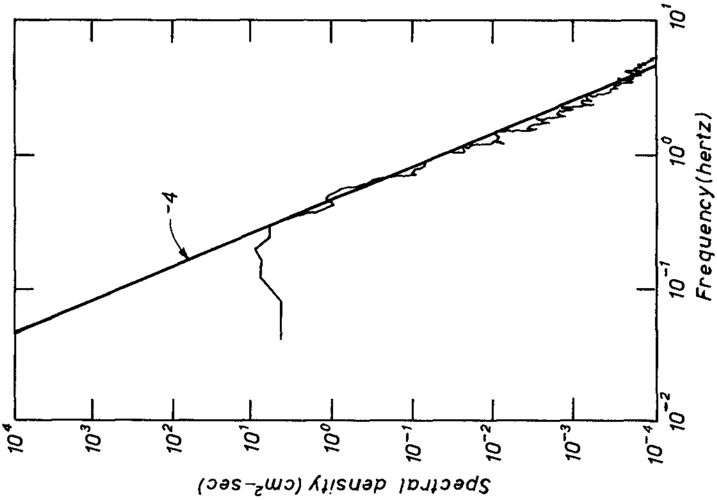

Fig. 7: EQUILIBRIUM RANGE IN INCIDENT WAVE SPECTRUM AT ST.4. WATER DEPTH AT BAR 40cm.

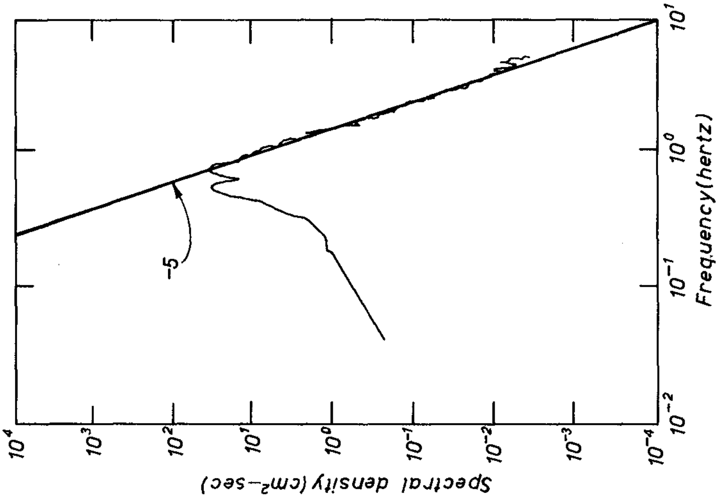

Fig. 8: EQUILIBRIUM RANGE IN RUN-UP SPECTRUM. WATER DEPTH OVER BAR 40cm.

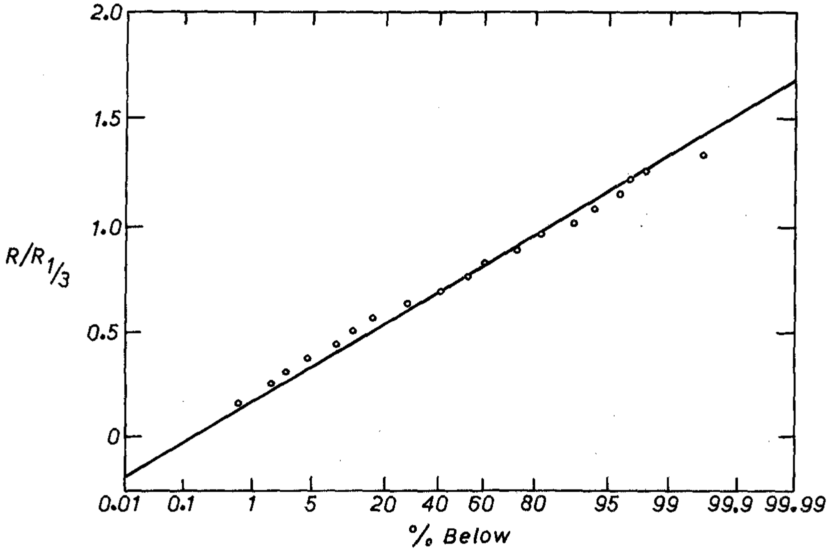

Fig. 9:—TYPICAL STATISTICAL DISTRIBUTION OF RUN-UP

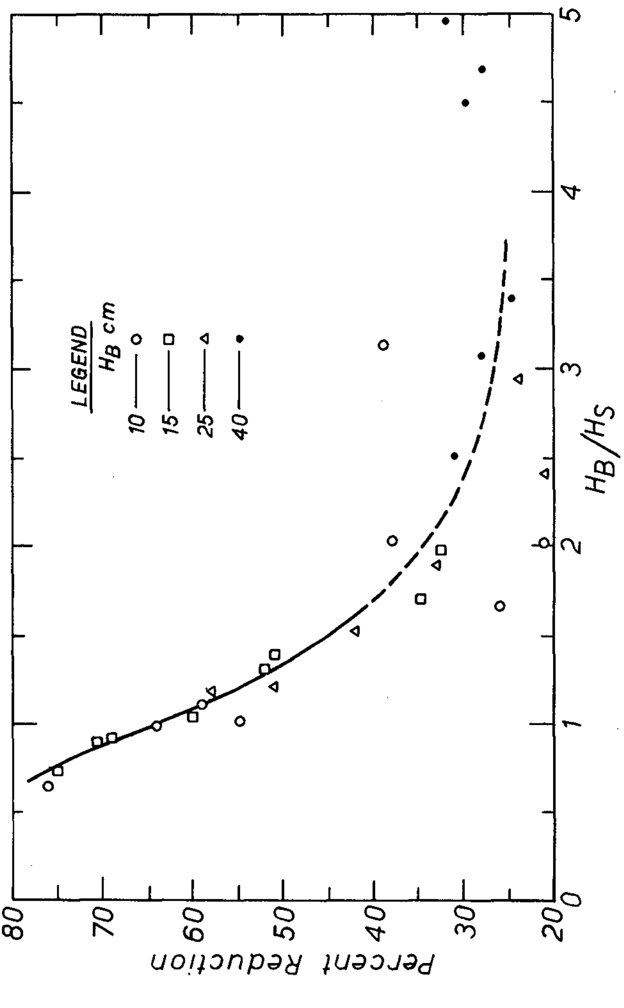

Fig.10:—PERCENTAGE REDUCTION IN ENERGY CAUSED BY THE PRESENCE OF THE BAR AS A FUNCTION OF WATER DEPTH AT THE BAR H_B DIVIDED BY THE SIGNIFICANT INCIDENT WAVE HEIGHT H_S

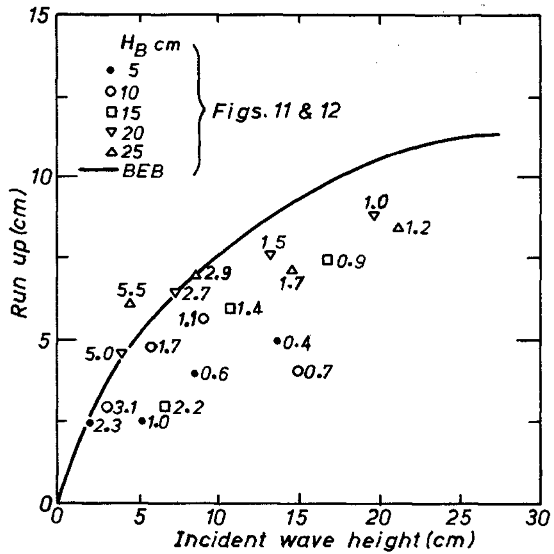

Fig. 11:—RUN-UP AS A FUNCTION OF INCIDENT WAVE HEIGHT (SINUSOIDAL WAVES). NUMBER BESIDE EACH POINT IS THE RATIO H_B/H_S

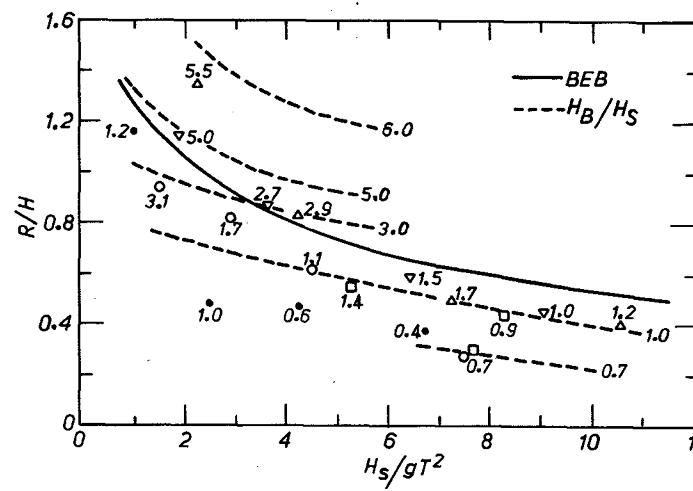

Fig.12: NORMALISED RUN-UP AS A FUNCTION OF INCIDENT WAVE STEEPNESS

values to be low and to the right. Although these points are barely sufficient to define contours of H_B/H_S, best contour lines are inserted to emphasize trends. The contours suggest that run-up heights can be either smaller or greater than the values predicted by the Beach Erosion Board formula depending on the ratio of water depth over the bar to the incident wave height. An examination of dominant wave height, period and beach conditions during a storm suggests that H_B/H_S is approximately 1.0 and the expected run-up is significantly below the value predicted by the BEB formula.

CONCLUSION

This study has revealed a number of important and interesting aspects of the run-up process occurring in the presence of an offshore bar. The following specific conclusions are derived:

1. The run-up is the product of a highly non-linear process acting on waves approaching a beach. The run-up process is dominated by turbulence generated by breaking waves and friction.

2. The offshore bar has a significant reducing effect on the run-up height. Resonance and seiching in the region between the bar and the slope can produce significant amplification in run-up and in some cases produce run-down.

3. Continued research is recommended on this problem to investigate the effects induced by movable beds and variable geometry on run-up. Run-up measurements should be made by implanting electronic contact elements in the surface along the beach slope. Field and laboratory studies will be necessary to arrive at adequate modeling relationships for proper prediction of the run-up height.

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