CHAPTER 115

WAVE SET-UP AND WAVE GENERATED CURRENTS IN THE LEE OF A BREAKWATER OR HEADLAND

Michael R. Gourlay
Department of Civil Engineering
University of Queensland, St. Lucia, Australia

ABSTRACT

Field and model observations indicate the existence of wave generated currents in the lee of breakwaters and headlands. It is shown by an idealised laboratory experiment that such currents could be produced by an alongshore gradient of breaker height with wave crests parallel to the beach. The mechanism for the generation of the current is explained together with some of its characteristics including its interaction with the wave set-up which causes it. It is further shown that it is possible to calculate by simple methods the hydraulic conditions causing the current. Currents produced by this mechanism appear to be of practical importance in determining the local plan shape of beaches close to breakwaters and headlands.

1. INTRODUCTION

The generation of unidirectional currents by waves in shallow water is now recognised as one of the fundamental mechanisms involved in the shaping of sedimentary coastlines. The action of waves breaking at an angle to a coast and so producing a current parallel to the shore and consequent alongshore movement of sand or littoral drift, has been widely known for many years. More recently the influence of mass transport currents induced by non breaking waves has also been recognised as a significant factor in coastal processes. Not so widely known is the process whereby currents may be generated parallel to the shoreline by breaking waves whose crests are also parallel to the beach.

Twenty-five years ago Irribarren (1) described a situation where a current was generated by swell waves whose breaking crests were parallel to the beach in a bay. Refraction analysis confirmed the visual observation that the breaker height decreased along the beach as the beach became more sheltered. The observed current flowed in the direction of decreasing breaker height. Although Irribarren was able to show the significance of this lateral expansion current, as he called it, in the interaction between coastal and fluvial processes at the mouth of a river at the sheltered end of the beach, it does not seem that much attention was paid to this process of current generation in the years immediately following the publication of his observations. However several years ago the present author was involved in conducting model investigations for several proposed small boat harbours in Queensland and nearby islands. During these tests it was observed that in many situations wave generated currents of considerable magnitude occurred. Closer analysis of some simple measurements and observations showed that while these currents generally increased with the magnitude of the breaking waves, it was quite obvious that they were not always formed by the classical littoral current mechanism of waves breaking at an angle to the shore.

2. SOME ACTUAL CASES

Since the publication of the observations made in fixed bed models (2a, 2b) some further situations where currents caused by alongshore gradients in breaker height occur have been studied. These situations, which include both field and model studies, give further information concerning both the nature and effects of such currents.

One situation is shown on figure 1. A rather steep beach (1 in 11 to 1 in 12) of medium to coarse sand (0.6 to 1.0 mm) is located on the weather side of a large enclosed bay where the tide range (approx. 2 m) is comparatively large in comparison to the height of the waves which break upon the beach. For winds from the predominant direction as shown, the southern end of the beach is sheltered from the resultant wave action. Wave refraction and diffraction produce an alongshore gradient in breaker height which may under certain conditions produce a reverse eddy current in the lee of the headland as shown in fig. 1. Further along the beach the effect of the breaker height gradient is balanced by the breaker angle effect tending to generate the classical littoral current. Consequently there is a null point of zero alongshore velocity at a place where the wave height is less than its value along the exposed portion of the beach.

In the preceding case the reverse current does not appear to be of great importance in the overall beach system behaviour. In figure 2 is shown a larger scale situation at Currumbin on the exposed southern coast of Queensland, Australia. The original situation is shown in figure 2b. Waves refracting and diffracting around the offshore rock had a noticeable angle with the shore and caused a sandspit to grow northward and push the mouth of the creek northwards until floodwaters cut a new channel near the headland and the process repeated itself. Experiments in a moveable bed model (figure 2a) showed that the building of a breakwater connecting the rock to the mainland reversed the current direction near the creek mouth causing a spit to grow southwards instead of northwards. Similar behaviour occurred when a connecting breakwater was built in the prototype.

The third example has already been discussed in reference 2b. Fig. 3a shows model observations of currents in the lee of a headland on the Queensland coast. An eddy was again observed and appears to be responsible for the formation of the shoal on the western side of the river mouth. Figure 3b shows that wave refraction will cause an alongshore gradient of breaker height which could generate such a current as suggested by the previous examples. On the other hand there is a second current generated along the northern side of the headland by waves breaking at an angle to the shore and it is possible that the circulating current is an eddy induced by momentum transfer from this second current. The process of current generation in the lee of a headland or structure is thus a complicated phenomenon dependent upon the local topography and wave conditions and intimately connected with variations in height, direction and location of the breaking waves.

3. WAVE SET-UP AND RADIATION STRESS THEORY

At about the same time as the observations described in reference (2a, 2b) were being made the phenomenon of wave set-up was beginning to receive attention by various investigators. It appears to have been first noticed in a

comparison of storm surge levels between sheltered and exposed areas during a hurricane (3). Subsequent field observations by Dorrestein (4) and laboratory studies reported by Saville (3) showed that significant increases in mean water-level occurred within the surf zone landward of the breakpoint. A smaller decrease in mean water level or set-down was also observed in the zone just seaward of the breakpoint. Subsequently increases in mean water level caused by the wave action were observed in lagoons and coral atolls and behind permeable breakwaters (5).

A theoretical explanation of the phenomenon of wave set-up and set-down as well as a unified approach to wave generated currents has been made possible by the work of Longuet-Higgins and Stewart (6 and 7) who introduced the concept of the "radiation stress" resulting from the changes in momentum flux within the wave system as the waves propagate over a shoaling bottom. The theory which is essentially a consideration of second order terms in the equations of motion, was put forward independently in a different form by Lundgren (8).

Subsequent laboratory experiments on a plane beach by Bowen, Inman and Simmons (9) showed that the theory of Longuet-Higgins and Stewart could be applied to the calculation of the set-down offshore of the breakpoint with the qualification that the maximum measured set-down was somewhat less than the theoretical due to the limitations of first order theory. Inshore of the breakpoint the set-up slope was found to be related to the beach slope and the mean ratio of wave-height to water depth within the surf zone. The magnitude of the set-up increases with the height of the breaking waves.

Moreover in recent years the radiation stress theory has been applied to several wave generated current and related problems. For instance Bowen (10) has considered the generation of longshore currents on a plane beach and the occurrence of rip currents (11). Longuet-Higgins (12 and 13) has also studied the longshore current problem, while O'Rourke and Le Blond (14) have calculated longshore currents in a semi-circular bay. The set-up within a coral atoll caused by waves breaking on the fringing reef has been treated by Tait (15). Longshore sand transport has also been investigated using this approach by Komar (16), while Bakker (17 and 18) has further considered the longshore sand transport problem in the situation where waves both break at an angle to the shore and have a longshore variation in wave height. Komar (19) has used the theory to explain how a stable equilibrium beach cusp formation can be maintained by a balance between the radiation stress component caused by waves breaking at an angle to the shoreline and the component caused by an alongshore gradient in breaker height.

4. LABORATORY INVESTIGATION

4.1. Purpose and Scope of Experiments.

Consideration of the various observations made in particular situations suggested that if the process of alongshore current generation by breaker height gradients were to be fully understood it would be necessary to make some systematic observations in a simplified situation where other current generating mechanisms were absent. The situation adopted for study after consideration of various alternatives was one in which an alongshore gradient of breaker height was obtained by diffraction of waves behind a semi-infinite breakwater parallel to the wave crests. The beach behind the breakwater was formed of concrete and was parallel to the undiffracted wave crests in the exposed zone outside the geometric shadow of the breakwater while in the sheltered zone behind the breakwater it wascurved with a constant radius centred on the breakwater tip. Since the diffracted wave crests have theoretical curves which can be approximated by a circle the influence of waves breaking at an angle to the beach was almost

completely eliminated. The general arrangement is shown in figure 4.

In this investigation the primary variable, the breaker height was measured for both the two dimensional (sheltered area blocked off) and the three dimensional system for several different incident wave heights at periods of 1.0 and 1.5 seconds. The water depth offshore of the beach was maintained at 20 cm in all cases. At the same time the resulting wave set-up was determined, together with the velocity and pattern of the unidirectional current flowing into the sheltered area. It was intended to treat the analysis of the system in two parts - one involving the relationship between the breaking wave characteristics and wave set-up and the other involving the "steady" non uniform flow relationship between the wave set-up and the current.

It should be particularly noted that the experimental arrangement permitted the study of a complete current system and so avoided some of the problems associated with studies of longshore currents where it is impossible to obtain the ideally desirable infinitely long beach and wave generator.

4.2. Measurement methods

Wave heights were measured using capacitance wave height meters of the insulated wire type, the wave trace being recorded on a twin channel pen recorder. Wave set-up was measured using 39 piezometers located at fixed points within the beach both offshore along lines perpendicular to the beach and inshore along the still water line. Piezometers were connected througha series of manifolds to an 8 tube air-water differential manometer in which the mean water level in the beach area could be obtained relative to that in the horizontal offshore section of the basin. Additional measurements of wave set-up were made at other locations using a probe made of 2 mm stainless steel tube which was placed normal to the beach and very close to it so that the opening was within the bottom boundary layer.

The wave generated current was observed and recorded using photographic methods. A movie camera was suspended above the test basin pointing vertically downwards and the paths of coloured floats recorded during a period of 2 to 2.5 minutes. A large number of almost neutrally buoyant floats were photographed in each sequence to cover the field of view. Selected float paths were then plotted from coordinates read off the film using a film analyser and current surface velocities deduced from the plotted data after the influence of the orbital velocities had been eliminated. All velocities quoted or shown on the various figures are average values determined over one or more wave periods.

In all cases the accuracy and consistency of the measurements were influenced by the fact that the test basin was located outdoors and so was subjected to uncontrollable variations in conditions due to the weather. In particular a close watch had to be kept on the water level and the effects of leakage and evaporation made good at approximate intervals.

4.3. Experimental Results

In this paper results are presented for a single incident wave condition (H_I = 9.0 cm, T = 1.50s), and the general characteristics of the current system are outlined together with various conclusions concerning its nature. The effects upon the current system of varying the incident wave conditions will be treated in a subsequent paper.

4.3.1. Wave Height and Wave Set-up.

The variation of wave height within the beach system is shown on figure 5. It is immediately evident from a study of the wave height contours that, while the wave height generally varies as would be expected from diffraction theory, there are also other factors influencing its magnitude. For instance in the exposed zone the occurrence of interference maxima and minima as predicted by diffraction theory can be recognised. However superimposed upon these is the effect of the wave reflected from the beach causing a pattern of nodes and antinodes more or less at right angles to the interference lines. Similar less recognisable effects occur in the sheltered zone. Nevertheless it is quite obvious that there is a very considerable alongshore gradient in breaker height.

The corresponding variation of mean water level within the system is shown on figure 6 and wave set-up profiles normal to the beach along four lines, are plotted on figure 7. It can be seen that the mean water level variations are of a larger order of magnitude within the surf zone compared with those offshore of the plunge point of the waves. Moreover variations in mean water level offshore of the breakpoint are consistent with those to be expected from application of "radiation stress" theory. In particular set-down occurs off the exposed portion of the beach and set-up within the sheltered area. Within the surf zone the wave set-up profile is straight and rises from the plunge point of the waves with a slope less than that of the beach.

Comparison of figures 5 and 6 immediately suggests that the wave set-up is generally proportional to the breaker height as was in fact found in two dimensional tests. Figure 8 shows the resultant alongshore gradients of breaker height and wave set-up within the surf zone. It is evident that the alongshore gradient of mean water level created by the wave breaking process provides the driving force for a current flowing into the sheltered area.

4.3.2. Wave Generated Current System

The current system itself is depicted on figure 9. The system is both simple in general form and complex in detail. The alongshore current commences within the surf zone in the exposed area outside the geometric shadow of the breakwater. It then flows parallel to the shore into the sheltered area after which it is deflected by the breakwater to flow back into the exposed zone to form a complete closed circuit. At the same time a smaller secondary eddy forms in the stagnation area near where the beach and breakwater intersect while the whole mass of water inside the main eddy is set in motion by the primary wave generated current.

Considered in more detail it is found that the extent of the wave generated current system coincides with the area affected by diffraction extending as far into the exposed zone as the first interference maximum of the wave height (figure 5). As figure 8 indicates this means that the wave generated current commences in the vicinity of the point where both wave height and mean water level have a maximum value. Outside this zone the interference effect causes variations in wave height and mean water level which result in the formation of a rip current as indicated in figure 9. In these experiments the characteristics of this rip current have not been investigated as its form is obviously modified by the side wall of the model basin.

The actual zone where water flows into the surf zone is located outside the geometric shadow of the breakwater. Here the water transported landward by mass transport currents offshore is projected by the breakers into the surf zone where the maximum alongshore gradient of mean water level exists. Both the velocity and discharge of the current increases up to a maximum in the vicinity

of the line of the geometric shadow of the breakwater where the primary current is still confined inshore of the break point (figure 10). Once inside the sheltered zone the current flows parallel to the beach until deflected at the stagnation point in the corner.

Typical horizontal velocity profiles are shown in figure 11. These are of surface velocities and any variation in surface velocity between crest and trough of the waves has been averaged out in the drawing of the profiles. Four profiles have been selected, one from the zone where the current is developing (profile 1), the others from the zone between where the current has reached its maximum discharge (profile 2) and where the maximum velocity passes offshore of the plunge point (profile 4). Each profile clearly shows how the current is concentrated parallel to the shore in the vicinity of the surf zone with a maximum velocity several times that of the induced eddy inside the primary current.

At profile 1 the current is completely confined inshore of the plunge point. However at profile 2, along the line of the geometric shadow of the breakwater, the primary current extends seaward as far as the breakpoint while the peak of the current is inshore of the plunge point. At profile 3, the primary current extends offshore of the break point. However the peak current velocity still occurs landward of the plunge point and since the latter has moved inshore and the depth has decreased the maximum velocity is greater. However, at profile 4 the situation appears to have reached a point of instability where the maximum current velocity oscillates between a point just inshore of the plunge point and a point offshore near the breakpoint. The inshore position of the maximum velocity appears to coincide with the uprush phase of the surf zone cycle and the offshore position with the backwash phase. This oscillation has not been investigated in detail but it was found (figure 10) that the maximum current velocity attains its greatest value just before it passes offshore of the plunge point. Furthermore while within the surf zone the maximum current velocity has a Froude number of the order of unity and a longitudinal section along the line of maximum velocity (figure 10) suggests a flow profile and energy gradient rather similar to a broadcrested weir with a drowned hydraulic jump on the downstream face in the vicinity of the breaker plunge point.

Observation of the flow and float paths also leads to the conclusion that a helicoidal secondary current is present within the main flow system. This appears to be generated in the zone where the current reaches its maximum discharge, i.e., near the geometric shadow of the breakwater, as the uprush and backwash of the breaking waves are carried alongshore by the primary wave generated current. A similar effect with rip feeder currents has been observed in the field by Eliot (20).

4.3.3. Summary of Wave Generated Current Types

The current system induced by diffraction at the breakwater produces four distinct types of unidirectional current. These are:-
- the initial inflow normal to the beach in the zone where the waves break and release their energy;
- the primary surf zone current which follows an approximate logarithmic spiral path in plan and has a helicoidal secondary current superimposed upon it;
- the induced secondary eddies within the sheltered zone, one within the main primary current circulation, the other within the stagnation zone near the base of the breakwater;
- the offshore mass transport current of the waves which is very greatly distorted by the circulatory current.

5. APPLICATION OF EXPERIMENTAL RESULTS

5.1. Simple Computation of Wave Generated Current

It is desirable for engineering purposes that the magnitude of the alongshore current can be calculated so that estimates of its significance as a sand transporting agent can be made. To do this it is necessary to be able to determine the following relationships:-
- the height and location of the breakers along the shore as a function of geometry and incident wave conditions;
- the wave set-up as a function of the breaker height;
- the current velocity as a function of the alongshore gradient in mean water level.

5.1.1. Computation of break point location

The variation in wave height within this system is a consequence of combined diffraction and shoaling. A first estimate of this phenomenon has been obtained using the generalised diffraction diagram for the case of the semi-infinite breakwater (figure 21 of reference 21) combined with small amplitude theory for computing shoaling effects.

The procedure adopted was to commence with the generalised diffraction diagram for constant water depth upon which are shown wave crests at intervals of one wave length and contours of the diffraction coefficient. Small amplitude theory was used to calculate the travel time of a wave crest of a given period up the beach, the calculation being made for small increments of distance x. From the latter computation, the positions of the wave crests at successive time intervals of one wave periodwere calculated taking the initial position as that of the breakwater tip. These distances were plotted upon tracing paper overlying the generalised diffraction diagram and the diffraction coefficient contours replotted in their correct relative positions along the relocated wave crests. The combined diffraction-shoaling coefficient K_{ds} was obtained by multiplying the value of K_d by the shoaling coefficient K_s appropriate to the depth in question. For convenience, this was done at points defined by the intersection of a given depth contour with a given K_d contour and the final combined diffraction shoaling diagram shown on figure 12 obtained by drawing contours of K_{ds}.

The combined diffraction-shoaling diagram shown as figure 12 is for a period of 1.0 seconds which is not the same as that used in the test reported in the preceding part of the paper, i.e., 1.5 seconds. Unfortunately limitations of the generalised diffraction diagram prevent its application in a system where only one or two wave lengths occur which is the case for the test results with 1.5s wave period. Moreover as discussed subsequently other questions arise which make it difficult to predict the location of the break point for these particular results. However, figure 12 has been used with empirical wave breaking data as correlated by Goda (22) to predict the location of the break point for waves of one second period and an incident height of 6.5 cm.

For comparison breakpoint locations observed on three separate occasions in the test basin with waves of similar height and period are also shown. The agreement is quite good in the exposed zone and the influence of the interference maximum upon the breakpoint location is similar in both cases. Discrepancies however appear in the exposed zone where the rip current flows seaward and in the sheltered zone where the alongshore current spreads out of the surf zone. Such discrepancies are not unexpected in these places.

5.1.2. Computation of wave set-up

In principle once the breaker location and height is known, the resulting wave set-up at the still water line, $\bar{\eta}_{swl}$, can then be calculated for a beach of a given slope as has been done for spilling breakers by Bakker (18). In practice there are problems. Firstly in the cases considered in this investigation all breakers in the zone of maximum alongshore gradient were plunging breakers. As shown on figure 7 wave set-up for this type of breaker begins at the plunge point and not at the breakpoint. It is thus necessary to be able to calculate the distance between breakpoint and plunge point x_p as well as to choose a suitable value of the breaker index $\gamma = \frac{H_b}{d_b}$.

Experimental data of Galvin (23) gives an estimate of the plunge point distance as a function of breaker height and beach slope. The following empirical equation relating these variables was obtained by Galvin.

$$\frac{x_p}{H_b} = 4.0 - 9.25 \tan \beta \qquad (1)$$

Using this equation and assuming a constant set-down between breakpoint and plunge point and shallow water conditions, consideration of simple geometry as was done by Bakker (18), gives the following relationship for $\bar{\eta}_{swl}$ referred to deepwater conditions.

$$\frac{\bar{\eta}_{swl}}{H_b} = \frac{\left\{3C^2 \left[1 - (4.0 - 9.25 \tan \beta)\, \gamma \tan \beta\right] - \frac{1}{2}\right\}\gamma}{3C^2\gamma^2 + 8} \qquad (2)$$

where $\gamma = \frac{H_b}{d_b}$

C is a factor defined by $\gamma' = C\gamma$ where γ applies at the breakpoint and γ' within the surf zone. β is the beach slope.

Application of the preceding equation to the test situation is complicated by the fact that the reference level for mean water level is different while the magnitudes of C, γ and the numerical constants are all subject to uncertainty. To avoid the influence of inaccuracies in the reference level in the test basin equation (2) can be modified to give the set-up relative to the mean water level at the breakpoint, $\bar{\eta}'_{swl}$

Thus

$$\frac{\bar{\eta}'_{swl}}{H_b} = \frac{3C^2\gamma \left[1 - (4.0 - 9.25 \tan \beta)\, \gamma \tan \beta\right]}{3C^2\gamma + 8} \qquad (3)$$

$\frac{\bar{\eta}'_{swl}}{H_b}$ as calculated from equation (3) is shown as a function of γ in figure 13, the constant C being assumed equal to unity. Experimental points from two dimensional tests at periods of 1.0 and 1.5s and various wave heights are also shown. The theoretical curve in general yields values of $\frac{\bar{\eta}'_{swl}}{H_b}$ about 10% below the experimental values. This can be considered to be quite good agreement in view of the large scatter in the selected experimental data used by Galvin to obtain equation (1).

Galvin (23), considering the kinematics of the plunging wave crest, also predicted theoretically that $\frac{x_p}{H_b}$ would be of the order of 2. Modification of equation (3) using $x_p = 2H_b$ gives

$$\frac{\bar{\eta}'_{swl}}{H_b} = \frac{3C^2\gamma\,[1 - 2\gamma \tan\beta]}{3C^2\gamma + 8} \qquad (4)$$

When plotted on figure 13, equation (4) coincides with the upper bound to the experimental data. Hence for these tests an average value of $x_p = 2.5\ H_b$ gives a fair estimate of the dimensionless wave set-up $\frac{\bar{\eta}'_{swl}}{H_b}$. Indeed, the relatively small influence of γ can well be neglected and a constant value of 0.2 assumed for $\frac{\bar{\eta}'_{swl}}{H_b}$, at least as a first approximation. The alongshore gradient of mean water level is thus theoretically calculable. The second step of determining the magnitude of the wave generated current from this gradient then follows.

5.1.3. Interaction between current and wave set-up

It has been found however that the relationship between breaker height and actual wave set-up is rather more complicated than it would first appear. Analysis of the experimental data indicates that the surf zone wave set-up in the system studied is the sum of at least four separate components. These are as follows:-

(i) equivalent two dimensional set-up for a given breaker height;
(ii) offshore set-up in the sheltered zone;
(iii) current set-up or superelevation resulting from centrifugal acceleration;
(iv) a displacement effect when the current is flowing within the surf zone caused by the wave uprush and backwash being carried along the beach by the current.

To these flow components which can be observed in the model must be added the effect of the alongshore gradient of radiation stress at the breakpoint which results in a further contribution to the wave set-up. The separation of these various factors influencing the wave set-up is dependent upon a knowledge of the alongshore primary current. Complete analysis of the test data for the case described in this paper is not yet available. Furthermore it appears that this particular set of data is subject to other complications due to the occurence of secondary waves which produce a further discrepancy between the two and three dimensional wave set-up in the exposed zone. It thus seems that it will be necessary to analyse the results of other wave conditions in more detail before a reasonable simplified method of calculation of the wave generated current can be evolved.

5.2. Inferences concerning Beach Morphology

From the point of view of sand movement and beach morphology it may be inferred that the circulatory wave generated current behind a breakwater or headland is a primary agent in determining the well known logarithmic spiral shape of beaches. In particular, erosion of the foreshore can be expected to occur in the zone just outside the geometric shadow of the breakwater where the

current is accelerating while accretion of the foreshore can be expected in the zone of deceleration associated with the stagnation eddy. Deposition is also likely outside the surf zone towards the centre of the induced eddy.

As in all sediment transporting systems changes in the bed configuration will induce changes in the hydraulic system until an equilibrium is set up. In this situation this may well include the development of an adverse bed gradient along the current path which will oppose the transporting action of the current on the bed material. Moreover the offshore contours and planform of the beach may be modified in such a way that the waves within the sheltered zone break at an angle to the shoreline and so provide a balancing dynamic force component to oppose the original alongshore current generated by the alongshore gradient of breaker height. This part of the process has not yet been investigated.

However in considering the morphological significance of these currents it is important that the relative scale of the system be considered. For the tests described in this investigation the input wave length is of the order of $\frac{1}{2}$ to 1/3 the size of the breakwater - beach system. This means that many of the factors influencing the current may well be exaggerated compared with conditions existing behind a real breakwater or headland. In this latter case then it is quite possible that simplified calculations may prove to be quite adequate to determine the magnitude of wave set-up and current velocity as the magnitudes of the interactions between the current and the waves will be quite small. On the other hand if groynes are under consideration then it can be expected that many of the interaction factors will be present and will need to be allowed for.

Finally it should be emphasised that this type of current does not produce the large scale log spiral beach plan forms discussed by Silvester (24) which result from an interaction between littoral drift and wave refraction when waves break at an angle to an initially straight beach. Such systems will however be modified by local alongshore variations in breaker height. These currents do however significantly influence the beach shape in the lee of any fixed structure or other fixed point and so shape the section of beach with greatest curvature. With no sediment supply coming round the breakwater or headland they will determine the beach shape completely. When sediment does come round the headland as in figure 2a the lateral expansion current will contribute to the development of the equilibrium plan form. When the latter is obtained however the reverse eddy will presumably disappear being replaced by a littoral current in the opposite direction with a transport capacity equal to the sediment supply.

6. CONCLUSION

The generation of currents of the lateral expansion type behind a breakwater by an alongshore gradient of breaker height when the wave crests are parallel to the beach has been reproduced in the laboratory. The basic mechanism producing the current has been shown to be an alongshore gradient of wave set-up within the surf zone. The resulting current is found to have a path in plan which appears to be log spiral in form and there is evidence of significant interaction between the current and the hydraulic conditions causing it.

Using a combination of theoretical and empirical methods it has been shown that it is possible to calculate the break point location for the particular test geometry considered and also to estimate the wave set-up from the breaker height for two dimensional plunging breakers. It thus appears that it should be possible to calculate the alongshore current in such a situation but full confirmation of this conclusion awaits the analysis of the complete test data.

It is evident that a current system of this type may be of primary importance in determining the alignment of a beach in the immediate vicinity of a breakwater, groyne or headland. Moreover it should be realised that the effects of breaker angle in generating a littoral current are always subject to modification by an alongshore gradient in breaker height regardless of the mechanism causing this gradient.

REFERENCES

1. Irribarren Cavanilles, R. Corrientes y transportes de arena originades por el oleaje. Revista de Obras Publicas, May - June 1947. French translation in Bull. de l'Association Internationale Permanente des Congrès de Navigation Vol. 23, 1949, pp. 100-132.

2(a) Gourlay, M.R. Wave generated currents - some observations made in fixed bed hydraulic models. Procs 2nd Australasian Conference on Hydraulics and Fluid Mechanics, Auckland, Dec. 1965.
(b) Also published in revised form as Univ. of Qld. Dept. Civil Engineering Bull. No. 7 Nov. 1965.

3. Saville, T. Experimental determination of wave set-up. Procs 2nd conference on Hurricanes, Miami, June 1961. U.S. Weather Bureau, National Hurricane Research Project Rep. No. 50, Mar. 1962.

4. Dorrestein, R. Wave set-up on a beach. Procs 2nd conference on Hurricanes, Miami, June 1961, U.S. Weather Bureau, National Hurricane Research Project Rep. No. 50, Mar. 1962.

5. Diskin, M.H., Vajda, M.L. and Amir, J. Piling-up behind low and submerged permeable breakwaters. Procs ASCE Vol. 96, no. WW2, May 1970 pp. 359-372.

6. Longuet-Higgins, M.S. and Stewart, R.W. Radiation stresses in water waves; a physical discussion with applications. Deep-Sea Research Vol. 11, 1964, pp. 529-562.

7. Longuet-Higgins, M.S. and Stewart, R.W. A note on wave set-up. J. Mar. Res. Vol. 21, 1963, pp. 4-10.

8. Lundgren, H. Wave thrust and wave energy level. Procs 10th I.A.H.R. Congress, London, 1963, Vol. 1, pp. 147-151.

9. Bowen, A.J., Inman D.L. and Simmons, V.P. Wave "set-down" and set-up. J. Geophys. Res. Vol. 73, 1968, pp. 2569-2577.

10. Bowen, A.J. The generation of longshore currents on a plane beach. J. Mar. Res. Vol. 27, 1969, pp. 206-215.

11(a) Bowen, A.J. Rip currents 1. Theoretical Investigations.
(b) Bowen, A.J. and Inman D.L. Rip currents 2. Laboratory and field observations. J. Geophys. Res. Vol. 74, 1969, pp. 5467-5490.

12. Longuet-Higgins, M.S. Longshore currents generated by obliquely incident sea waves. J. Geophys. Res. Vol. 75, 1970, pp. 6778-6801.

13. Longuet-Higgins, M.S. Recent progress in the study of longshore currents. Chapter in Waves on beaches and resulting sediment transport. Ed. R.E. Meyer Academic Press, 1972, pp. 203-248.

14. O'Rourke, J.C. and Le Blond, P.H. Longshore currents in a semicircular bay. J. Geophys. Res. Vol. 77, 1972, pp. 444-452.

15. Tait, R.J. Wave set-up on coral reefs. J. Geophys. Res. Vol. 77, 1972 pp. 2207-2211.

16. Komar, P.D. The mechanics of sand transport on beaches. J. Geophys. Res. Vol. 76, 1971, pp. 713-721.

17. Bakker, W.T. Littoral drift in the surf zone. Rijkswaterstaat, Directorate for Water Management and Hydraulic Research, Department for Coastal Research. Study Report WWK 70-16, 1970.

18. Bakker, W.T. The influence of longshore variation of the wave height on the littoral drift. Rijswaterstaat, Directorate for Water Management and Hydraulic Research, Department for Coastal Research. Study Report WWK 71-19, 1971.

19. Komar, P.D. Nearshore currents and the equilibrium cuspate shoreline. Oregon State Univ., Dept. Oceanogr. Tech. Rep. 239, May 1972.

20. Eliot, J. The persistance of rip current patterns on sandy beaches. Engineering Dynamics of the Coastal Zone. I.E. Aust., 1st Australian Conference on Coastal Engineering, Sydney May 1973, pp.29-34

21. Shore Protection, Planning and Design. U.S. Army Coastal Engineering Research Center. Tech. Rep. No. 4. 3rd. ed. 1966.

22. Goda, Y. A synthesis of breaker indices. Trans. J.S.C.E., Vol. 2, Part 2, 1970, pp. 227-230.

23. Galvin, C.J. Breaker travel and choice of design wave height. Procs A.S.C.E., Vol. 95, No. WW2, May 1969, pp. 175-200.

24. Silvester, R. Stabilization of sedimentary coastlines. Nature, Vol. 188, 1960, pp. 467-469.

LIST OF SYMBOLS

d - water depth

d_b - water depth at breakpoint

H - wave height

H_b - wave height at breakpoint

H_I - wave height incident to breakwater - in this case measured in water depth d = 20 cm

H_o - deepwater wave height

$K_d = \frac{H}{H_I}$ - diffraction coefficient

$K_s = \frac{H}{H_I}$ - shoaling coefficient relative to water depth d = 20 cm

$K_{ds} = K_d \cdot K_s$ - combined diffraction-shoaling coefficient relative to water depth d = 20 cm

T = wave period

x_p = distance between breakpoint and plunge point

β = beach slope angle

$\gamma = \frac{H_b}{d_b}$ - breaker index

$\gamma' = C\gamma = \frac{H}{d}$ within surf zone landward of plunge point

$\bar{\eta}_{swl}$ - wave set-up at still water line relative to still water level in deep water

$\bar{\eta}'_{swl}$ - wave set-up at still water line relative to mean water level at breakpoint.

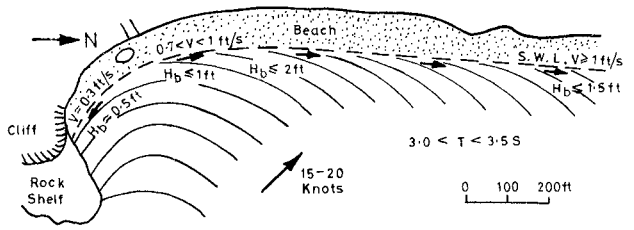

Figure 1

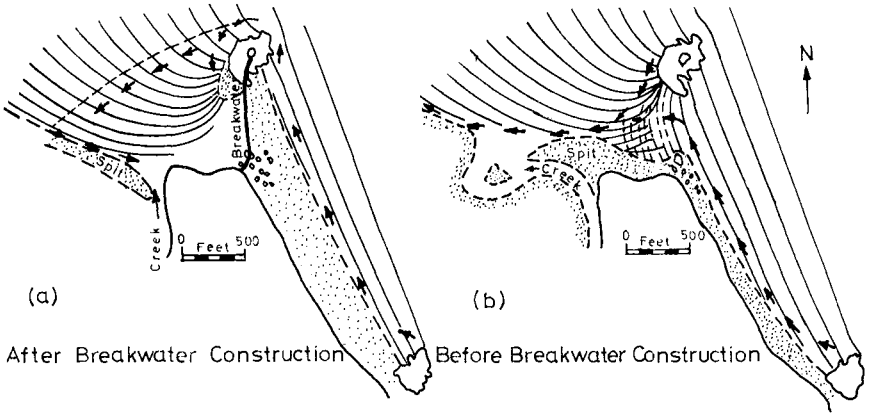

Figure 2

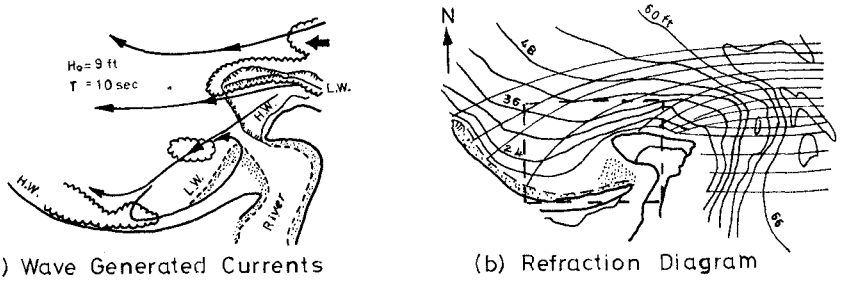

Figure 3

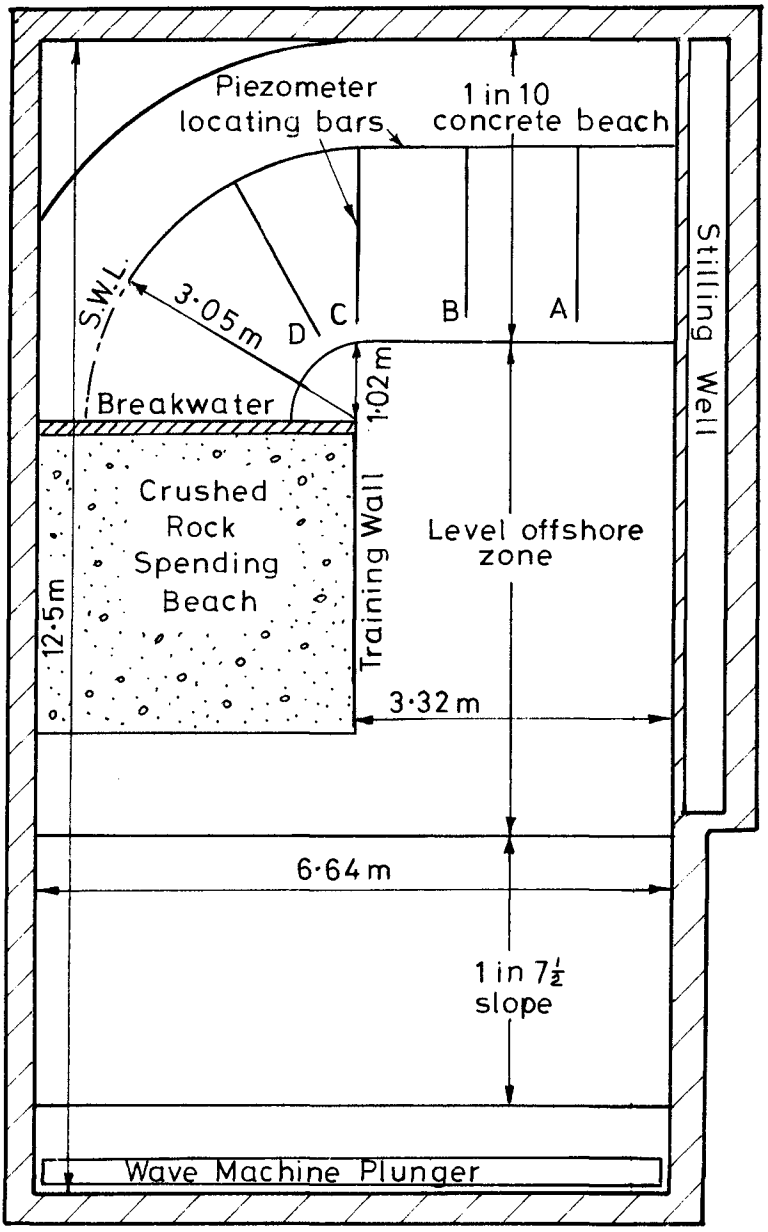
Piezometer
locating bars
1 in 10
concrete beach
Stilling Well
S.W.L.
3·05m
D
C
B
A
Breakwater
1·02 m
Crushed
Rock
Spending
Beach
Training Wall
Level offshore
zone
12·5m
3·32 m
6·64 m
1 in 7½
slope
Wave Machine Plunger

Figure 4

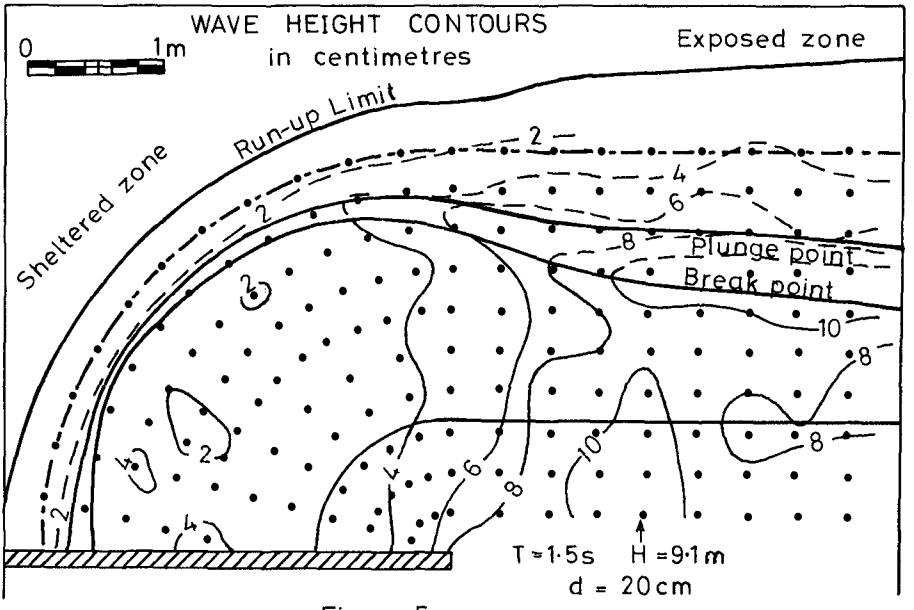

Figure 5

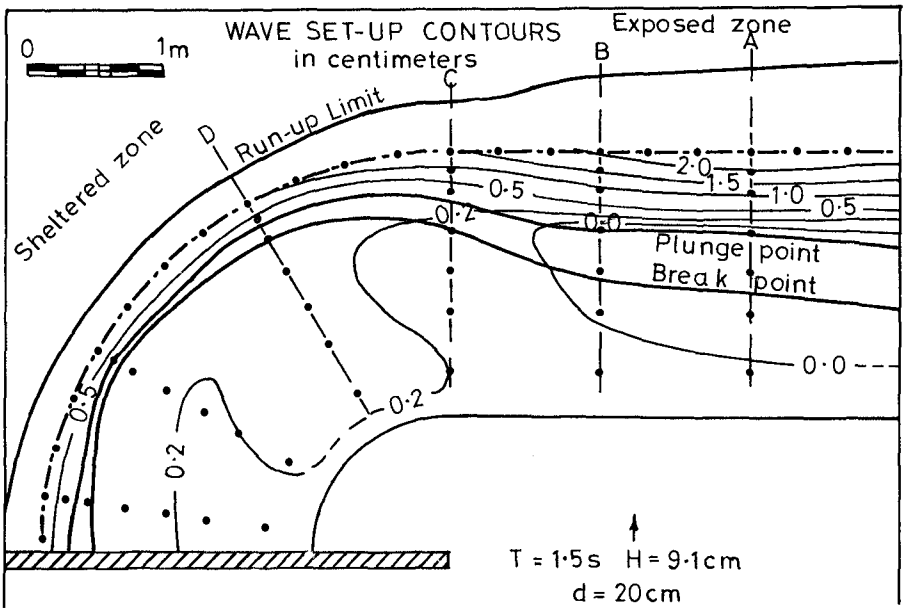

Figure 6

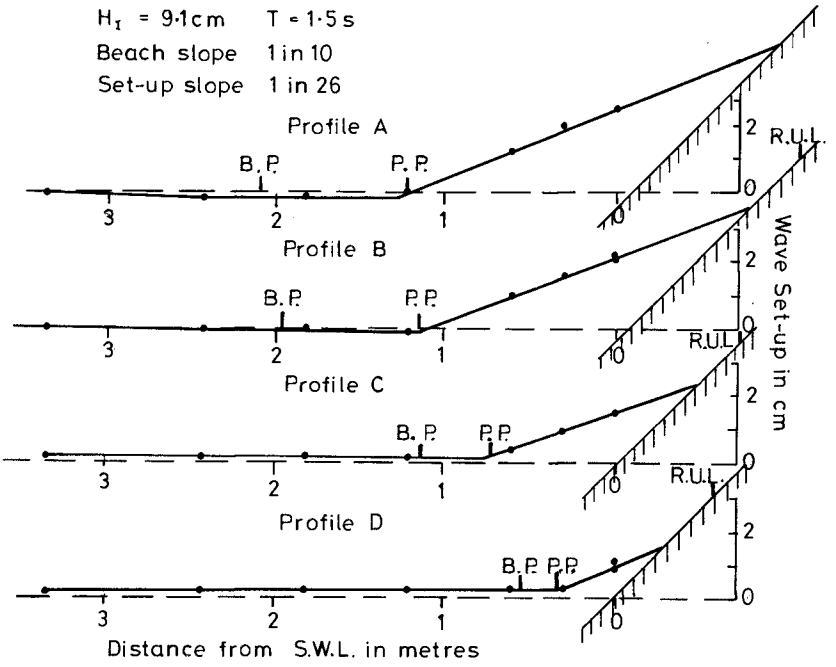

Figure 7

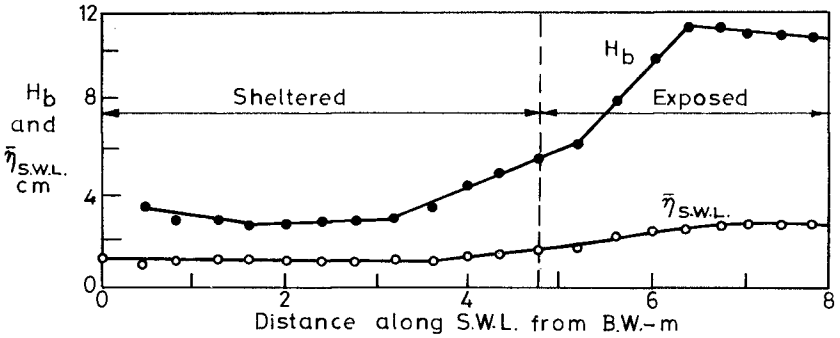

Figure 8

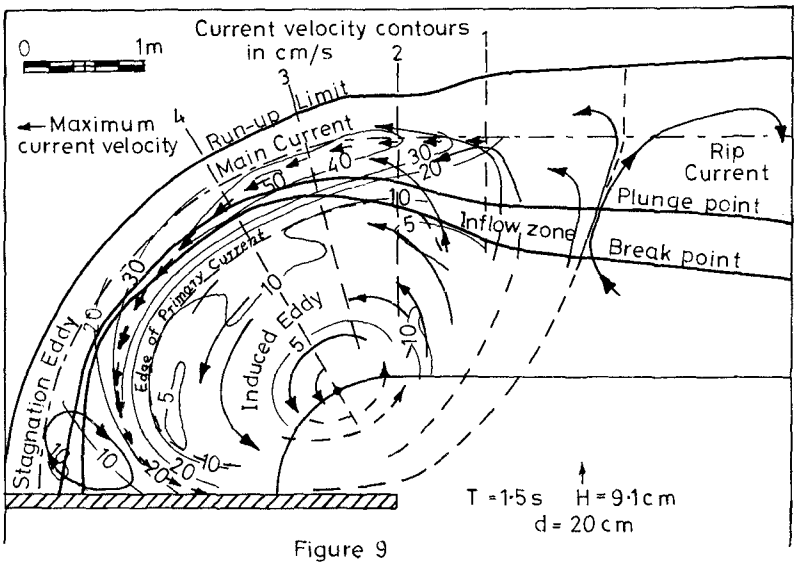

Figure 9

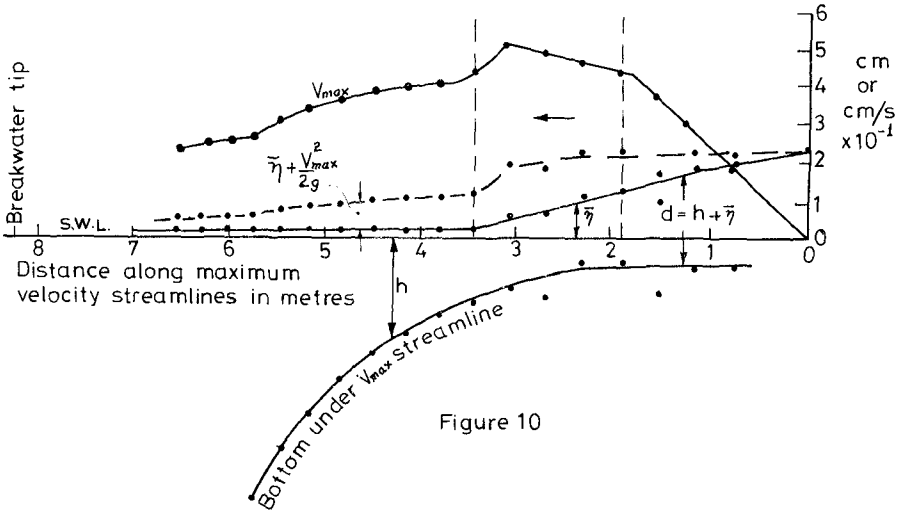

Figure 10

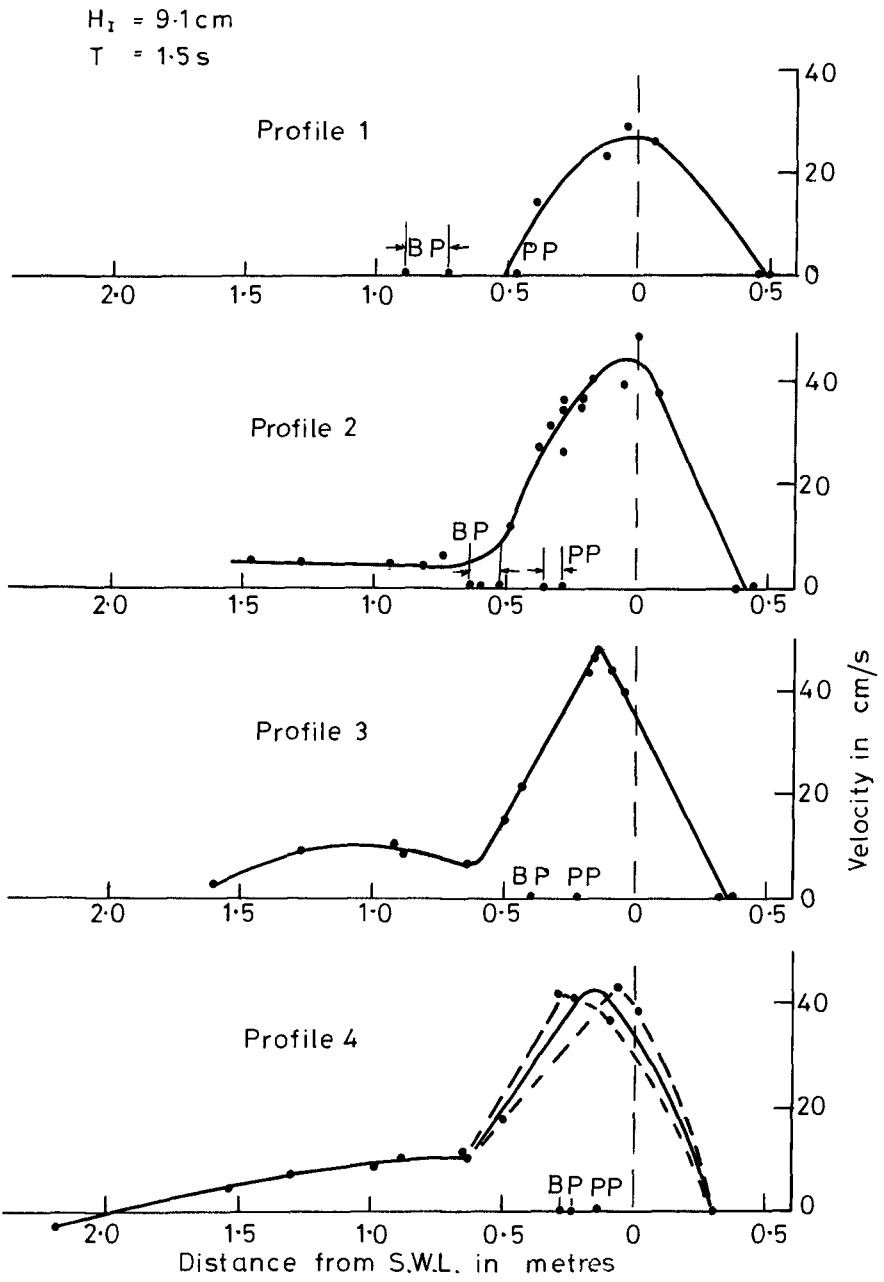
H_I = 9·1 cm
T = 1·5 s
Profile 1
BP
PP
Profile 2
BP
PP
Profile 3
BP PP
Profile 4
BP PP
2·0
1·5
1·0
0·5
0
0·5
40
20
0
Velocity in cm/s
Distance from S.W.L. in metres

Figure 11

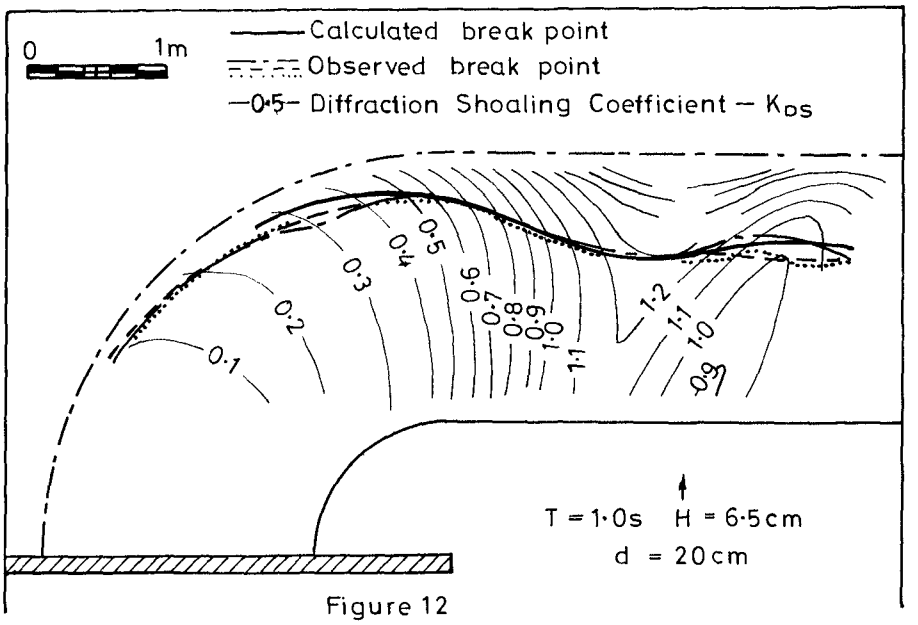

Figure 12

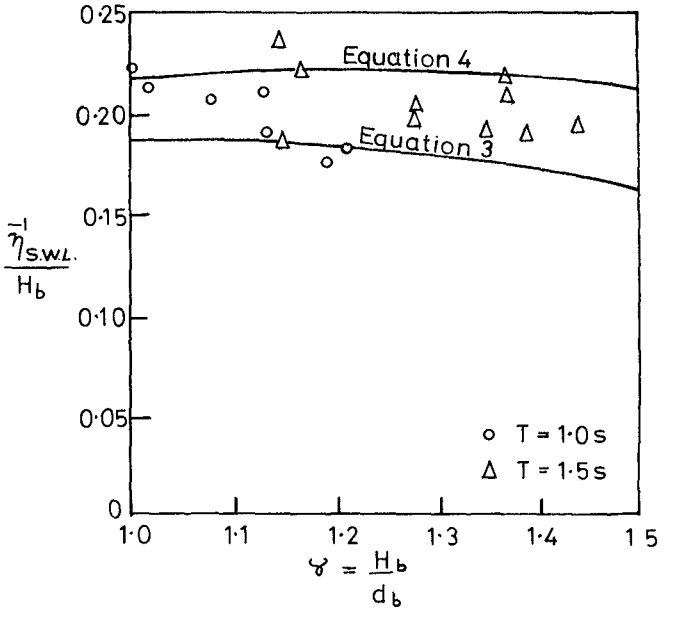

Figure 13