AN INSTANTANEOUS MEASURE OF THE STRENGTH OF A BREAKER: "FOOT AND TOES"

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Abstract:

Development of suitable averaged boundary conditions for a free surface that is disturbed by strong turbulence leads to consideration of the origin of turbulence in a breaker, especially where the water falling down the front meets smooth water. A simple consideration of the averaging and a variation on the usual terminology leads to an instantaneous measure of breaker strength.

We consider spilling breakers, bores and the fully breaking bow waves of moving vessels. The masses of water tumbling down the front of such breakers fall onto the smooth incoming water at the leading edge of the breaker, which is where the major generation of turbulence takes place. Traditionally this is usually envisaged as a ‘‘roller” riding on the front of a wave meeting smooth water at its foot. In a paper that stimulated, or informed, a number of experimental measurements (e.g. Battjes & Sakai, 1981; Stive, 1980, 1984), Peregrine & Svendsen (1978) pointed out that the turbulent flow in a spiller can not easily be separated into a "roller" and the rest. There is a stream of turbulence initiated at the foot of the spiller, from which a roller can only be divided once mean streamlines are determined. Also the fluctuating velocities are just as large as the mean velocities. Hence, we choose not use the term ‘‘roller": though the concept is useful in indicating forward flow in the surface layer down the face of a breaker. We use "breaker" instead. We are keen to be able to model unsteady waves, and for such waves there is then no unambiguous way of determining a separation streamline to define a roller’s boundary.

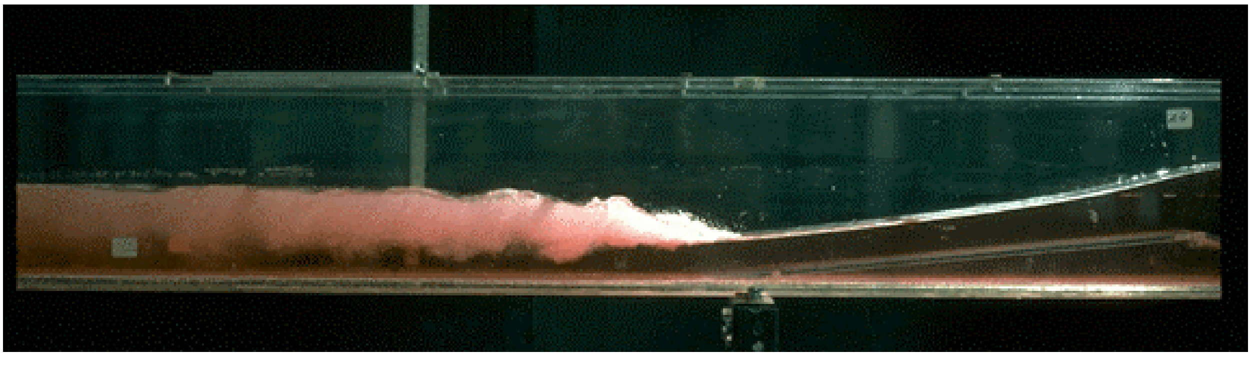

Figure 1. Turbulence at a hydraulic jump revealed by the mixing of a layer of tiny bubbles originally on the surface of the undisturbed water flowing over a weir.

There is another piece of traditional terminology that it seems advisable to change. The forward edge of a breaker’s turbulent splashing front is sometimes referred to as the "toe" of the breaker. Measurements, especially of hydraulic jumps, show a continuous mean surface through the breaker at this point. However, there are problems in defining a mean surface at an unsteady irregular boundary as the turbulent flow moves over the smooth surface in front. A very similar problem discussed in Brocchini & Peregrine (1996, §3) for the swash zone on a beach and the same ideas hold in this problem. If one considers the mean height of water as one moves through from smooth water to a breaker there is a smooth transition as mentioned, and a sperceived in figure 1. However, if one looks from above at the breaker's boundary it is not smooth and an averaging along the base of the breaker will give a mean position for the base of the breaker which is not the same as where its mean profile departs from the smooth water surface. We propose that a mean position for base of a breaker, however determined from the three-dimensional character of the turbulent flow, should be called the "foot" of the breaker. In addition we propose that the fluctuations of the boundary between smooth and turbulent flow at the water surface be called the ''toes" of the breaker, see figure 2. The effect of this is that at the foot of the breaker there is a finite depth of water above the smooth water level.

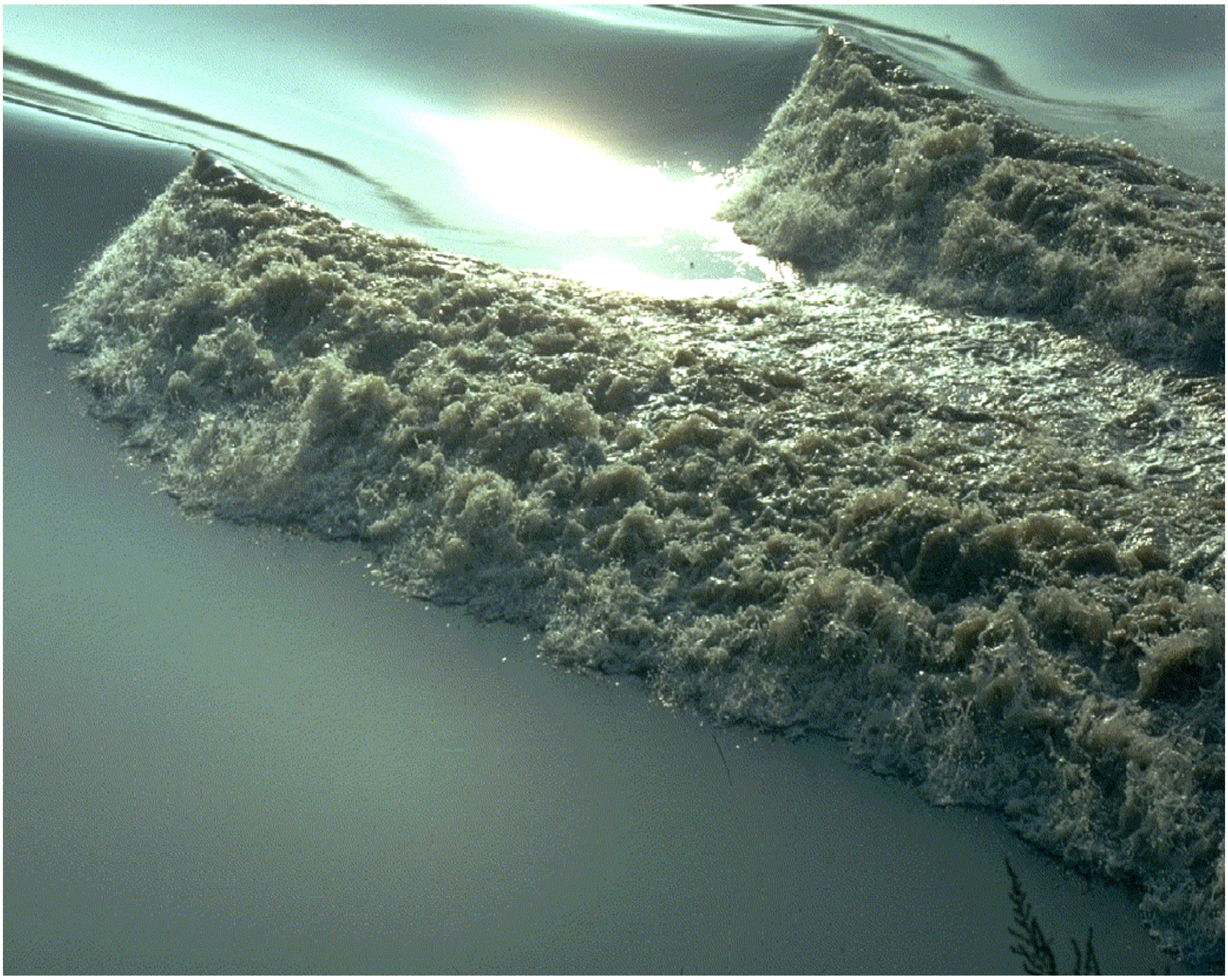

Figure 2. Turbulence and splashing of breaking waves (part of a tidal bore in the River Severn) showing the non-uniformity of the foot of the breakers..

This apparently simple change of terminology brings with it a real benefit to the modelling of breakers. There are problems in defining the strength of a breaker. For example, comparisons are often made with hydraulic jumps of the same height in order to estimate dissipation, with varying success The concept of a breaker foot, with toes fluctuating around it, may be combined with results from our study towards defining free surface boundary conditions in the presence of strong turbulence (Brocchini & Peregrine 2000a,b). Strong turbulence at a water-air free surface can lead to splashing and a disconnected surface as in a breaking wave. In Brocchini &

Peregrine (2000b) we approach from the Reynolds averaging ideas common in turbulence. Averaging to obtain boundary conditions for such flows first requires equations of motion for the two-phase region which we designate as a "surface layer". These are derived using an integral method, then averaged conservation equations for mass and momentum are obtained. Boundary conditions appropriate for use with averaged equations in the body of the of the water are obtained by integrating across the two-phase surface layer. A number of terms arise for which closure expressions must be found for practical use. Knowledge of the properties of strong turbulence at a free surface is insufficient to make such closures. However, preliminary discussions are given for two simplified cases in order to stimulate further experimental and theoretical studies.

Two dominant parameters appear from our analysis. One is the equivalent depth of the surface layer, d, i.e. the thickness of water in the two-phase layer, the other is its mean velocity, U. Thus, given the position of a breaker's foot, the two-phase layer at that point yields, at least, these two parameters, which may be used as a measure of breaker strength. Such measures are in principle functions of time for unsteady breakers, and hence appropriate parameters for unsteady modelling. Much work needs to be done to learn what suitable closure equations shpuld be for these surface layer variables.

One possible approach to parameterisation at the breaker's foot would be to follow up Peregrine & Svendsen's (1978) suggestion that the primary generation of turbulence occurs at the foot of a breaker in a similar manner to a mixing layer. This is not quite the traditional mixing layer that has been the subject of many studies clarifying its turbulent structure, since the velocities of the two layers that come together at the breaker's foot are in opposing directions relative to the foot rather than in the same direction, or with one being at rest. Thus breaker turbulence is initiated in a more violent fashion, especially since one of the layers is already strongly turbulent. Indeed a measure of the size of the "toes" may also be a useful strength parameter for this turbulence. However, an extrapolation of mixing layer data would be a sensible starting point until comparisons with more relevant experimental data becomes possible.

At present we are unaware of any measurements of an appropriate type at a breakers foot. There are, of course, substantial difficulties in making measurements in a splashing environment, though for small breakers, up to about 3cm in height, surface tension ensures a smooth surface, so measurements may be easier. However, we hope that we may stimulate such studies.

The "foot and toes" concept seems sound at over a wide range of scales. At large scales there is substantial splashing of blobs of water, as may be seen when viewing a breaker head on at near water level. At small scales surface tension restrains the blobs so that there is no splashing but as shown there are still significant toes. It is only at the smallest scale where ripples might ride ahead of the breaker that the toes may be smoothed. Even so figure 3 shows two small breakers, one with ripples and one without, where the turbulence is strong enough to cause the three-dimensional irregularites.

Our suggestion is that the two variables, d and U, at the breakers foot ar worthy of further investigation, both experimentally and as parametets in models of breakers.

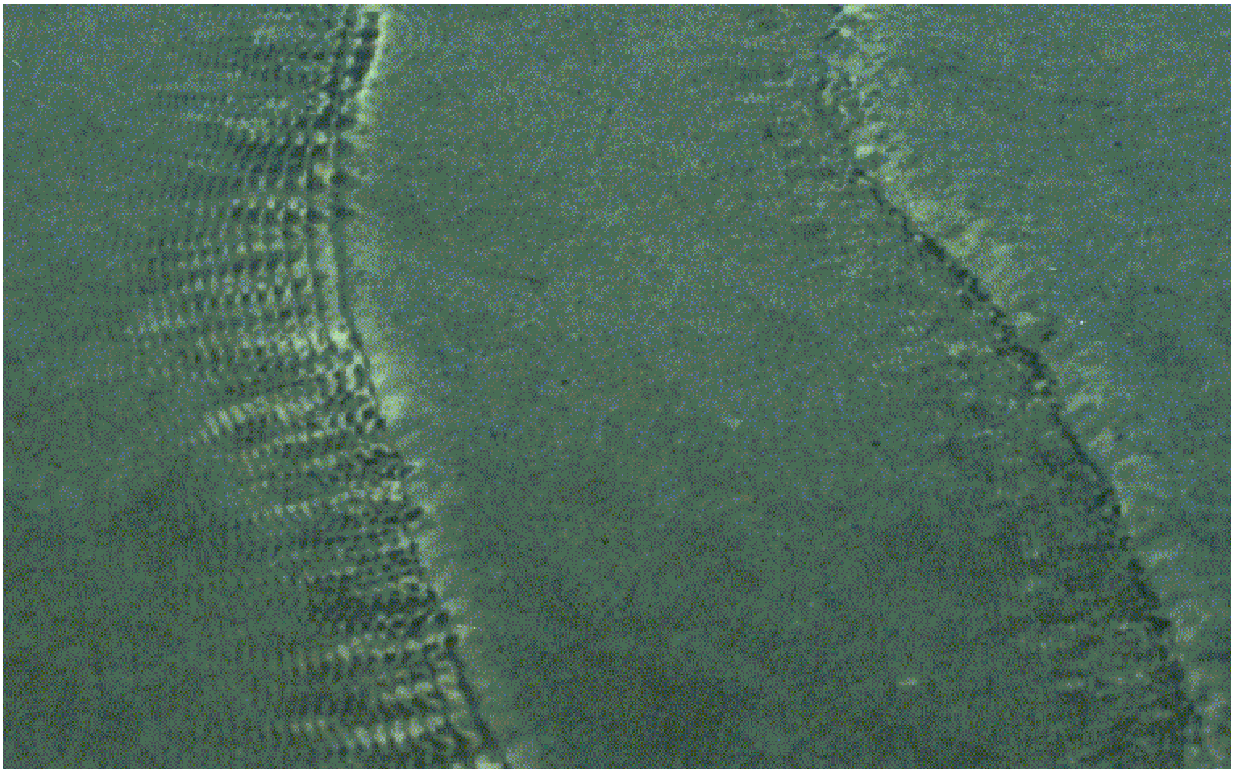

Figure 3. Turbulent breakers dominated by capillary effects. The left-hand wave shows how turbulent fluctuations influence the amplitude of ripples, whereas the turbulence overwhelms ripple production for the right-hand wave.

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