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The backwash vortex

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A backwash vortex has been observed under waves running up a sloping bed. The vortex is formed at the edge of the swash zone when backwash turns back into an oncoming wave bore. The vortex eroded a bed consisting of glass beads, and formed a step which induced the formation of sand ripples.

1. Introduction

A step is often observed at the boundary between surf and swash zones on a beach. This is known as the beach step. Figure 1 shows a line in a surging breaker formed when backwash runs into an oncoming wave front. It was observed that under this breaker the beach step ran parallel with the shoreline and sand ripples extended offshore from the step. It has been considered likely that the formation of a beach step is exclusively due to breakers. However, a detailed observation of flows under the breakers indicates that there may be a different cause. This paper is concerned with the results of visual, qualitative studies of the step formation.

2. Experimental methods

Experiments were carried out by using a water tank as illustrated in figure 2. The tank, made of transparent plastic plates, was 150 cm long, 15 cm wide and 30 cm deep. The tank was equipped with a sloping flat bed of 90 cm in length. The slope θ of the bed from the horizontal could be varied between 4° and 10°. Wave bores climbing up the sloping bed were formed by oscillating a wave generator with a motor–crank system. The stroke d of the wave generator and the frequency f were respectively less than 8 cm, at a still water level, and 0·8 Hz.

Glass beads of specific gravity 2·43 and mean diameter 0·028 cm were used as an erodible bed material, whose layer about 6 cm thick covered the sloping flat bed. Wet sawdust slightly heavier than water was used to visualize the flows below breakers. A vertical slice of water above the sloping bed was illuminated with a 1 kW light projector. Flows and sedimentary profiles in the slice were photographed through a side wall of the tank by using a 35 mm camera, which was at rest with respect to the tank.

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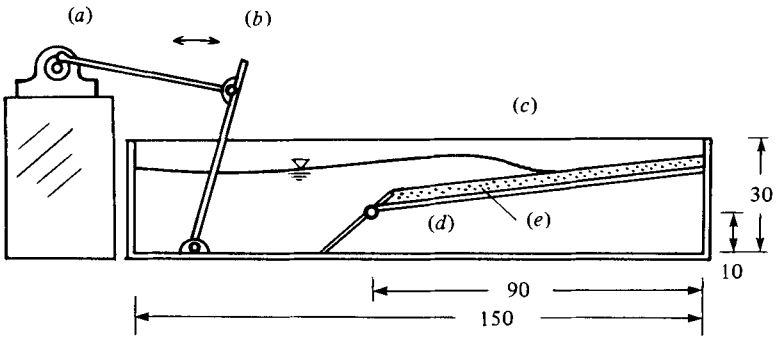

FIGURE 2. Schematic diagram of experimental set-up (dimensions in cm). (*a*) Motor; (*b*) wave generator; (*c*) water tank; (*d*) sloping flat bed; (*e*) glass beads.

3. Results and discussion

Figures 3(*a*), (*b*), and (*c*) show respectively surging, intermediate, and plunging breakers at different values of f. Under all these breakers a vortex rotating anticlockwise is formed on the sloping flat bed, where the backwash turns back into a bore running up the bed. The vortex may properly be called a backwash vortex. It should be noted here that the formation of wave bores in backwash on beaches was discussed by Peregrine (1974).

A backwash vortex formed when the first backwash ran into the wave bore following it. The vortex is shown in figure 4; the sawdust on the flat bed was lifted up by the backwash vortex, not by the breaker.

Figure 5 shows a process in which a backwash vortex erodes the bed of glass beads and forms a step, t being the time elapsed since the start of the oscillatory water motion. The water is at rest in figure 5(*a*). Figure 5(*b*) shows that the backwash vortex, rotating anticlockwise, is formed when backwash runs into a wave bore. Figure 5(*c*) shows a flow with a clockwise rotating vortex when a bore has run up the bed. As water oscillations continue, the backwash vortex scours material from the erodible bed, causing a step to grow up gradually. Such a step may be called the backwash step.

Once the backwash step is formed, the flow separates at the lower edge of the step, and another separation vortex is there induced. This vortex induces a ripple mark on the 'offshore' side of the original backwash step. Figures 5(*d*)–(*f*) show that this process continues until the entire surface of the lower bed is rippled with sand ripples extending in the 'offshore' direction. The wavelength of the ripples decreases in that direction. Figures 5(*d*) and (*e*) show the flow patterns at approximately the same phase of the wave motion as that of figure 5(*b*). Figure 5(*f*) shows that the bore running up the bed after backwash has turned back into it; the stationary step and ripples shown in this figure were almost two dimensional. The results so far described indicate that a step such as shown in figure 1 is formed due to the backwash vortex.

It should be noted that Davis & Fox (1971) and Davis (1978) have investigated a step which develops on a foreshore and call it the plunge step, the formation of which is ascribed to the final plunge of waves before their surging up on a beach face. As far as the plunge step is ever caused directly by the plunge of waves, the backwash step so far discussed seems different from it.

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FIGURE 1. Surging breaker formed when the backwash turns back into a wave front at Itoshima, Fukuoka. Step height and wavelengths of sand ripples were about 15 cm and 30 cm, respectively. The coast is to the right.

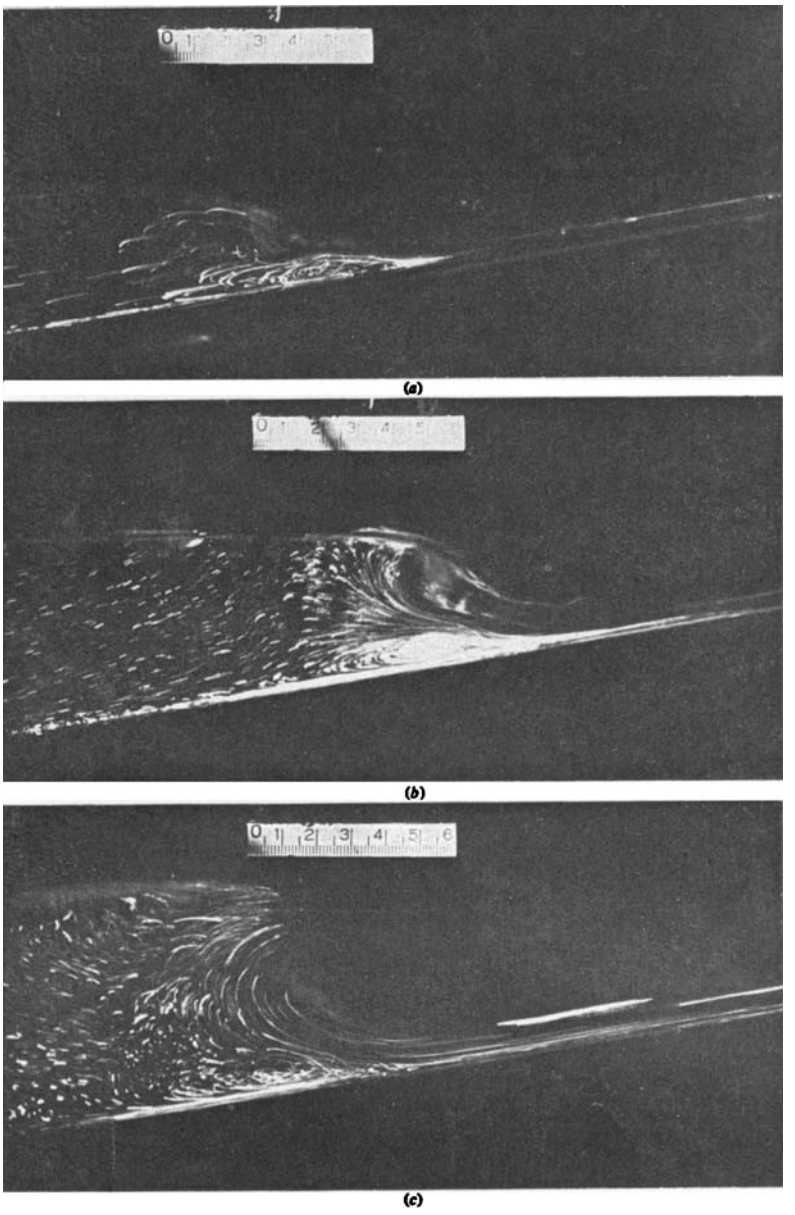


FIGURE 3. Backwash vortices under breakers ($\theta = 8{\cdot}7^{\circ}$, $d = 7{\cdot}6$ cm, scale: 6 cm). (*a*) $f = 0{\cdot}46$ Hz; (*b*) $f = 0{\cdot}51$ Hz; (*c*) $f = 0{\cdot}63$ Hz.

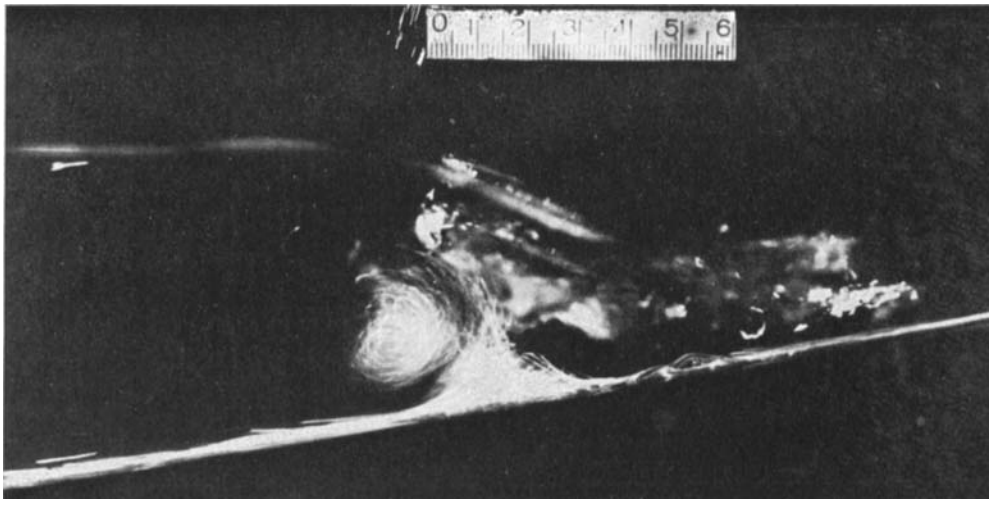
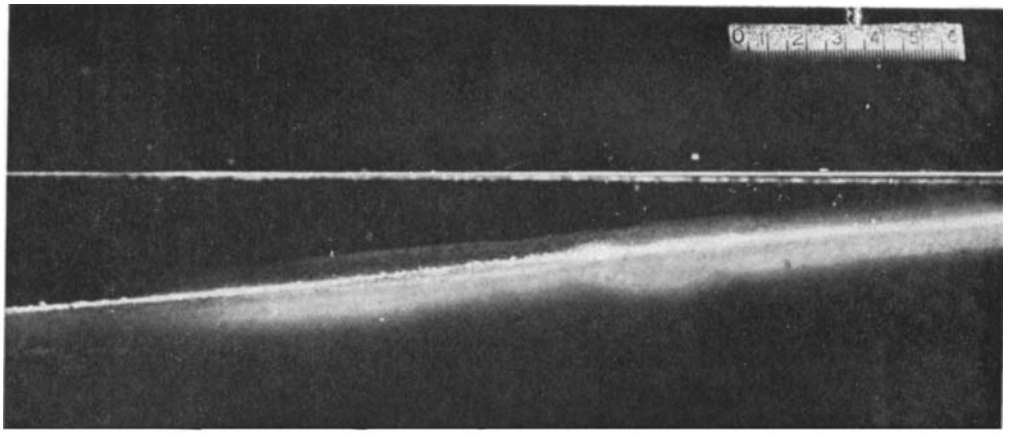
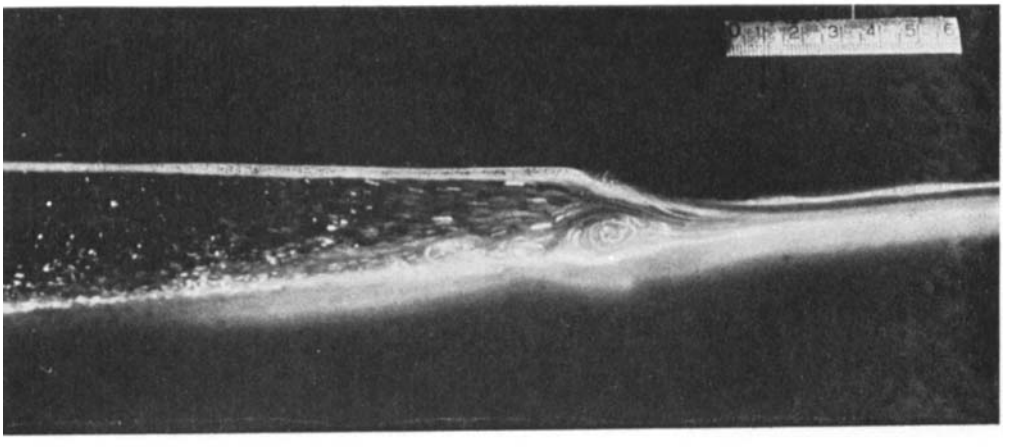


FIGURE 4. Lift-up of sawdust by a backwash vortex
($\theta = 8{\cdot}7°$, $d = 7{\cdot}6$ cm, $f = 0{\cdot}71$ Hz, scale: 6 cm).

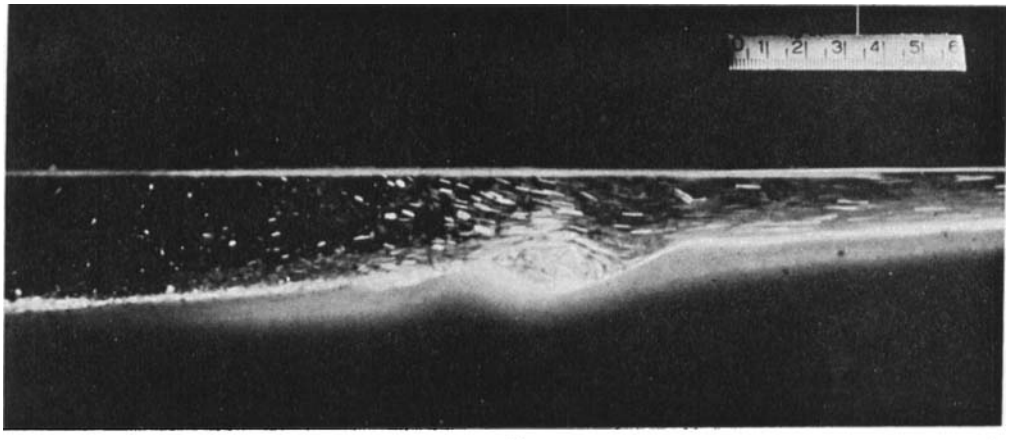


(*a*)

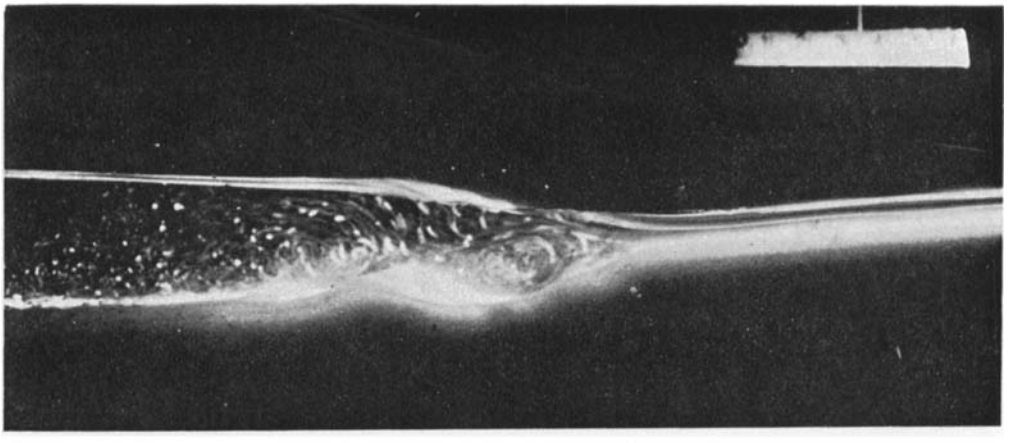


(*b*)

FIGURE 5 (*a*, *b*). For legend see plate 5.

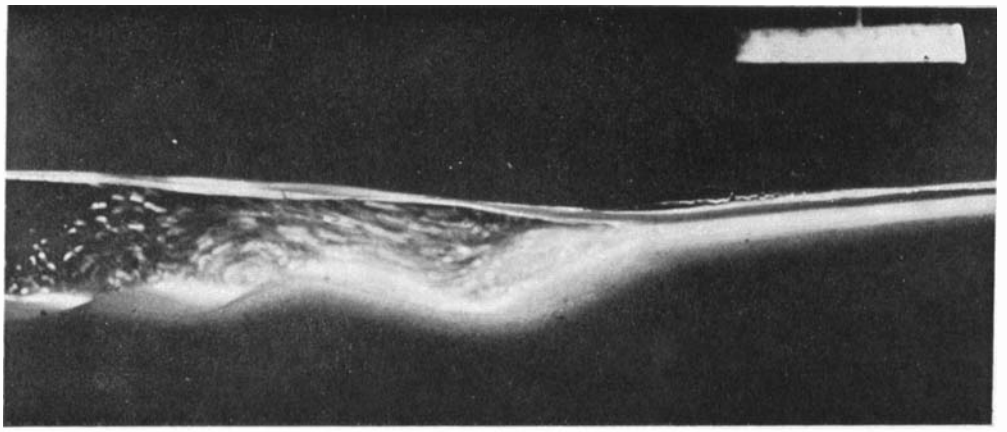


(*c*)

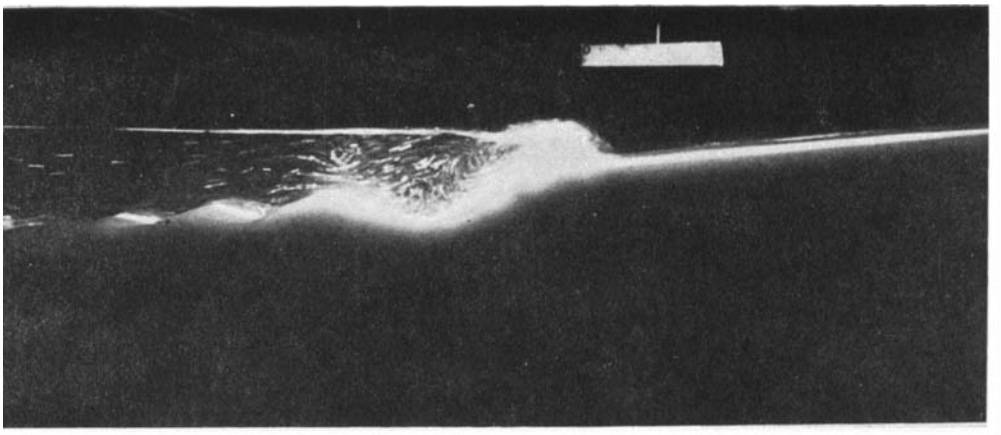


(*d*)

FIGURE 5 (*c*, *d*). For legend see plate 5.



(*e*)



(*f*)

FIGURE 5. Formation of a backwash step and sand ripples ($\theta = 5{\cdot}5°$ at $t = 0$ s, $d = 4{\cdot}7$ cm, $f = 0{\cdot}44$ Hz, scale length = 6 cm). (*a*) $t = 0$ s; (*b*) $t = 27$ s; (*c*) $t = 1$ min; (*d*) $t = 2{\cdot}5$ min; (*e*) $t = 10$ min; (*f*) $t = 12$ min.