BREAKING INTERNAL BULGES

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NOTE

BREAKING INTERNAL BULGES

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Some results of a visual study of breaking internal solitary bulges of gravity current types forming on an interfacial transition region in fresh and salt waters are reported. An internal backwash vortex was found to form when a bulge breaks down on a sloping floor.

Key Words: Internal bulge, Gravity current, Breaking bulge

1. Introduction

The behavior of internal solitary bulges forming in stratified fluids has recently been a subject of much theoretical and experimental interest[1)~4)]. There are two types of bulges; an internal solitary wave and an internal vortex pair[5)6)]. The internal solitary wave is composed of open streamlines and known to behave as an internal solition. The internal vortex pair is composed of closed streamlines, and a fluid enclosed in the closed vortical region moves with the speed of the vortex pair.

In a preceding paper[4)], two of us reported that an internal bulge, perhaps being of a vortex pair type, is formed by a solitary gravity current released from one end of a water tank. This note reports the results of preliminary observations of the breaking of solitary internal bulges formed by gravity currents on an interfacial transition region of fresh and salt waters.

2. Experimental Methods

Experiments were carried out using a 15×20×200 cm water tank, of which details are described also in the preceding paper[4)]. Two cases of the bulge breaking were observed; the breaking following the head-on collision of two bulges and the breaking on a slope. The head-on colli-

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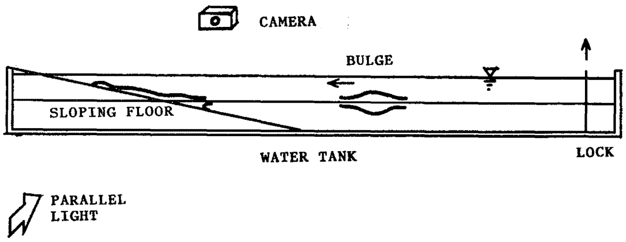


Fig. 1 Eeperimental set-up.

sion of internal solitary waves was investigated by Pao and Kao[7].

In the head-on collision experiments, two bulges (one rightward traveling and the other leftward traveling) were released from two locks attached to both ends of the tank, and made to collide at the middle of the tank. In the breaking-on-slope experiments, the bottom floor of the tank tilted from the horizontal or a sloping plate attached to one end of the tank was used as a slope; Fig. 1 shows the tank equipped with the sloping plate.

A typical salt concentration profile is displayed in Fig. 2. The salt concentration was determined by measuring the electric conductivity of waters. The fractional density difference $\Delta\rho/\rho_0$ as defined in ref. 4 was between 0.01 and 0.07; $\Delta\rho$ is the density difference between upper fresh and lower salt waters, and ρ_0, written as ρ_1 in ref. 4, is the fresh water density.

The variation of salt concentration with the passage of a solitary bulge is displayed in Fig. 3, which indicates that the bulge entails regular internal waves behind it. When the tank was set to be horizontal and no sloping plate was attached to the tank, the bulge repeated reflections in the tank until it faded away. Flow visualization was made by means of the shadow-graph method and partly the electrolytic precipitation method.

3. Head-on Collision

A typical process of the head-on collision of two vortex-pair type bulges is displayed in Fig. 4: t is the time passed after the generation of bulges. Figure 4(a) shows the two bulges approaching each other. Figure 4(b) shows the colliding bulges. A vertical streak in the middle of the bulges indicates that there occurs no conspicuous fluid mixing of the two bulges. Figures 4(c) and (d) show the bulges traveling apart from each other. It should be noted that, as far as we take notice of only the displacements of pycno-boundaries showing the phases of bulges, the two bulges appear as if they had changed their positions with each other when colliding.

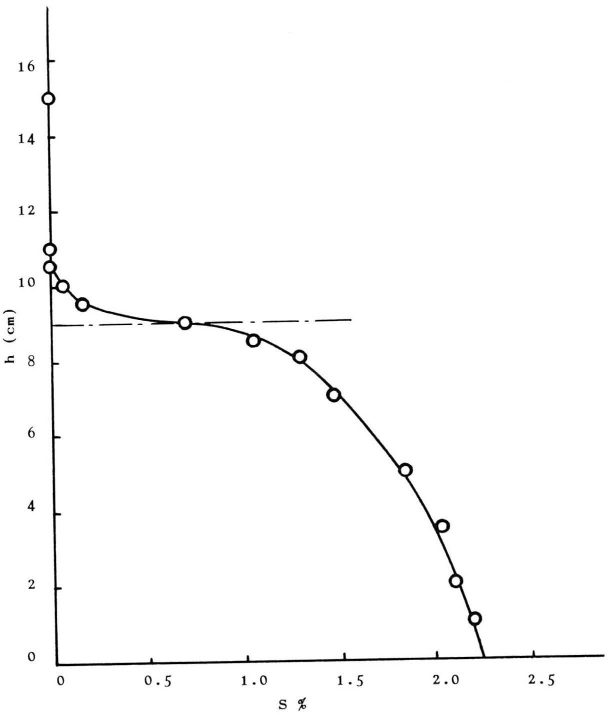


Fig. 2 A salt concentration profile with *h* being the height measured from the bottom of tank.

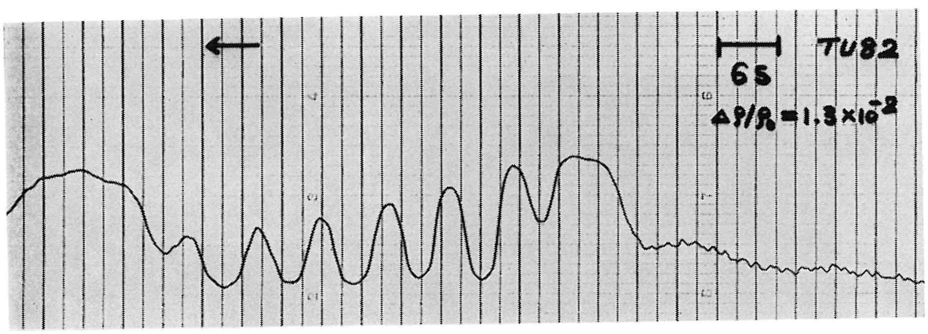
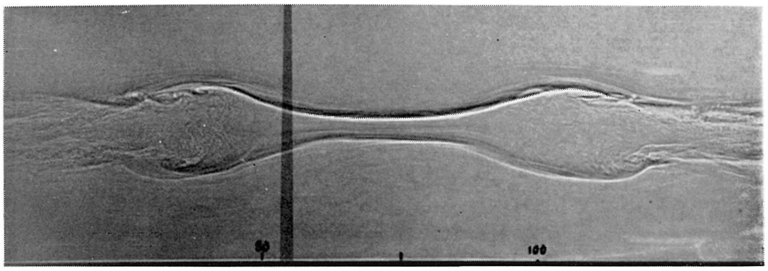
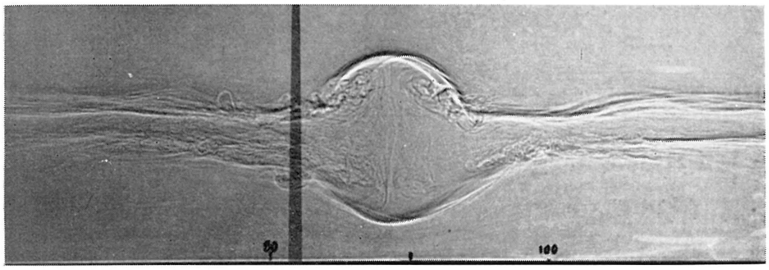


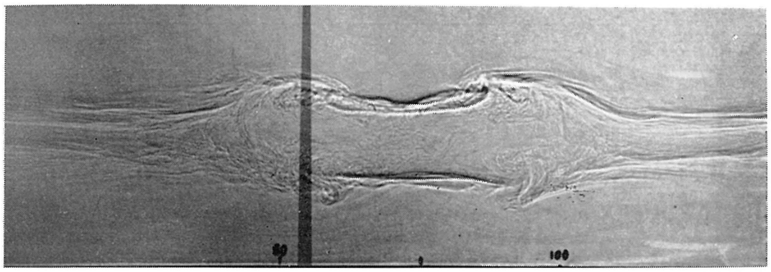
Fig. 3 Variation of salt concentration with the passage of a bulge. Time increases from right to left.



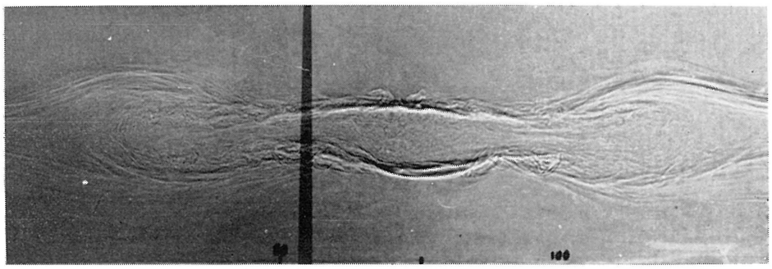
(a) $t=63$ s



(b) $t=66$ s,



(c) $t=69$ s,



(d) $t=72$ s

Fig. 4 Head-on collision of two bulges at $\Delta\rho/\rho_0=0.033$; scale unit in cm.

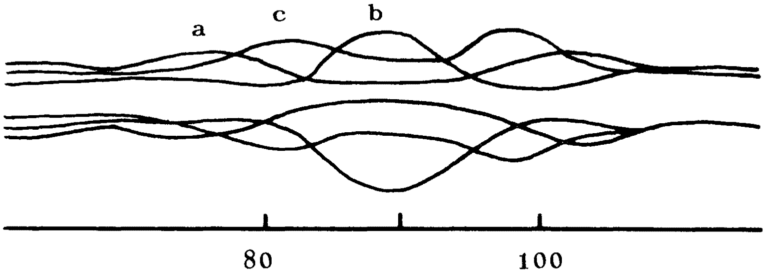


Fig. 5 Time-wise variation of boundary forms of the bulges shown in Fig. 4; unit in cm.

Figure 5 illustrates the time-wise variation of the bulge forms shown in Figs. 4(a) - (c).

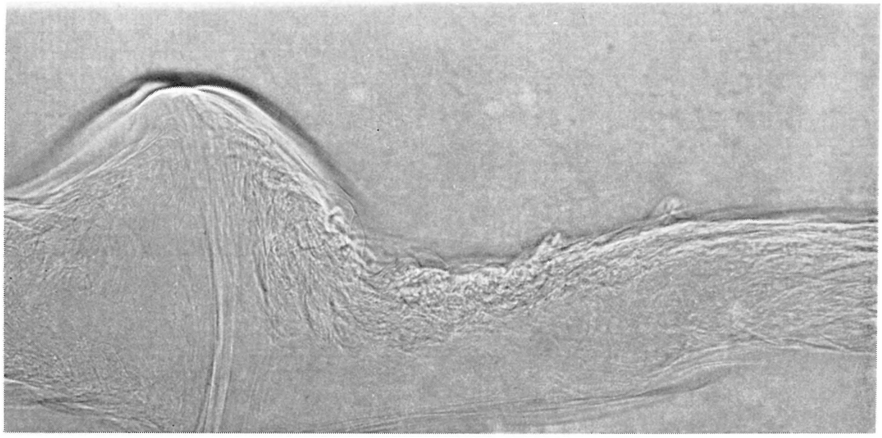
The breaking of bulges takes place when the bulges begin to turn back halfway after their collision. Figure 6 shows a similar process in a magnified scale. Figure 6(a) shows colliding and peaking two bulges, and Fig. 6(b) the breaking of an upper portion of the bulge which is about to turn back to the right. As seen from Fig.6(b), the breaking occurs in the rear of the bulge crest.

4. Breaking on a Slope

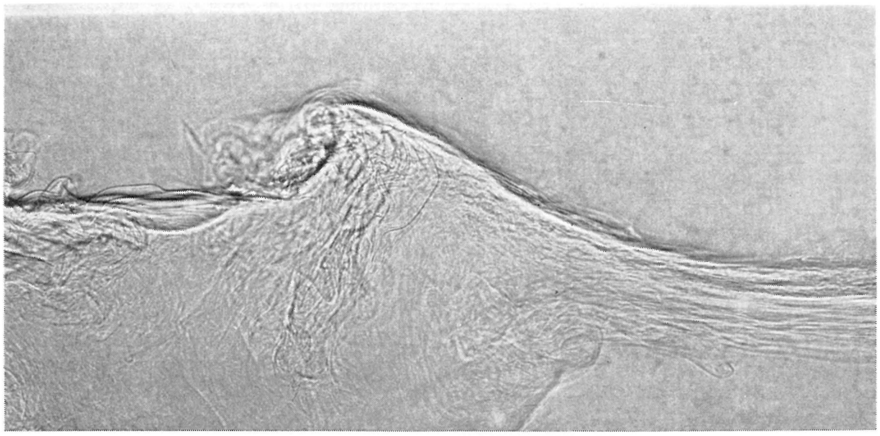
A typical process of the bulge breaking on a slope is displayed in Fig. 7. Figure 7(a) shows an initial system of stratified waters. Figures 7(b) - (d) show the first run-up of the bulge along the sloping floor. As seen from Fig. 7(c), a gravity flow head forms at the front of the bulge. The main breaking of the bulge occurs at the second stage of the run-up shown in Figs. 7(e) - (h). As compared with a spearing front of the first run-up, the front of the second run-up appears rather dull as seen from Fig. 7(f). The latter thick front cannot run up to the position reached by the first run-up front, and collapses into turbulence as shown in Figs. 7(g) and (h). Figure 7(g) shows that some portion of the turbulent water runs down the slope. Such a turbulent flow could have considerable influences on the deformation of erodible sea beds. The internal waves following the bulge cause smaller scale run-ups.

Figure 8 summarizes the above process of bulge breaking on a slope.

Figure 9 shows also the process of breaking of a bulge on a slope; the bulge was visualized with the electrolytic precipitation method. The distortion of the upper interface is seen clearly. A peculiar feature is the appearance of a backwash vortex, which forms on a slope when the bulge front turns back into the lower water; see Fig. 9(c). This backwash vortex is similar to the one which forms when the surface waves turn back into a nearshore water[8]. The formation of this internal

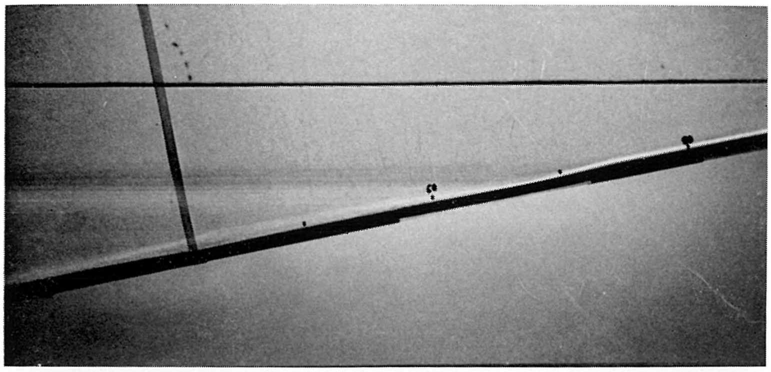


(a) $t=24$ s

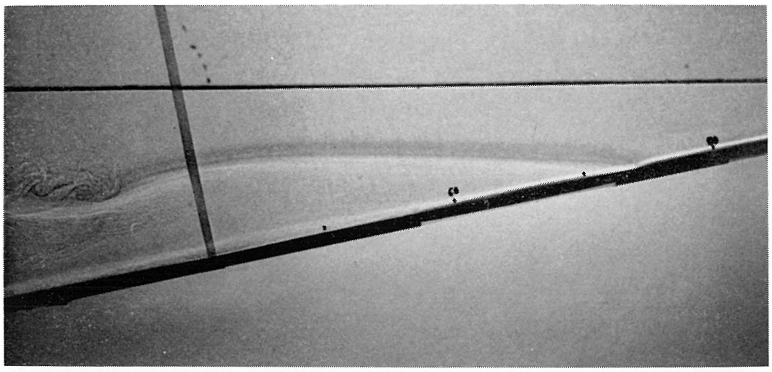


(b) $t=27$ s

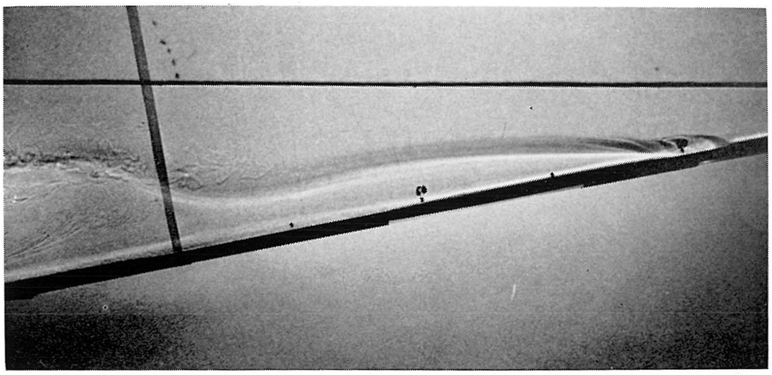
Fig. 6 Breaking of a colliding bulge (in a magnified scale) at $\Delta\rho/\rho_0=0.016$.



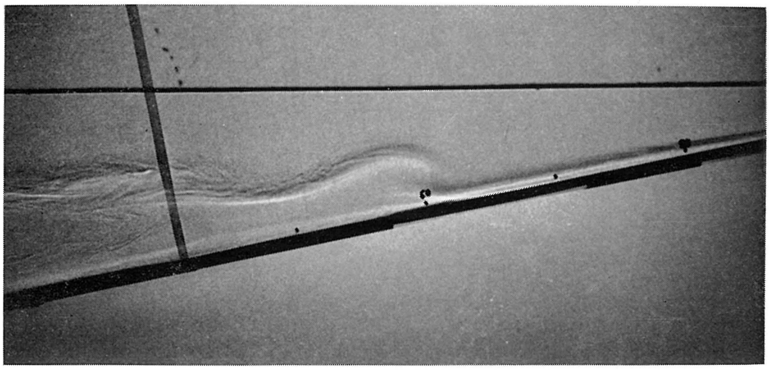
(a) $t=0$ s



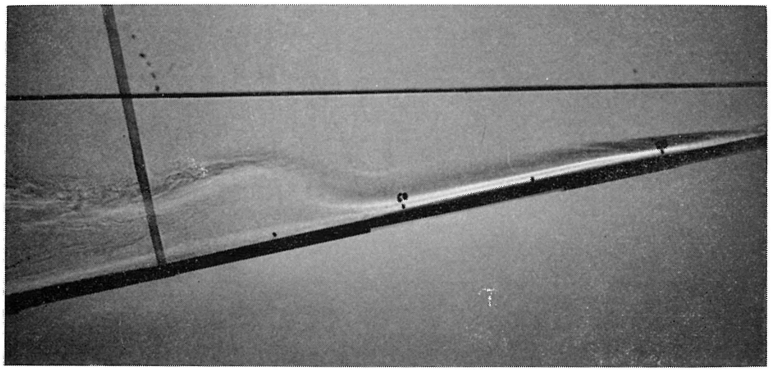
(b) $t=10$ s



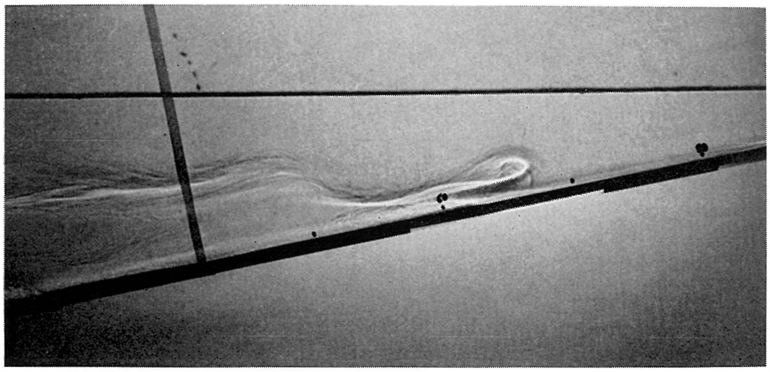
(c) $t=12$ s



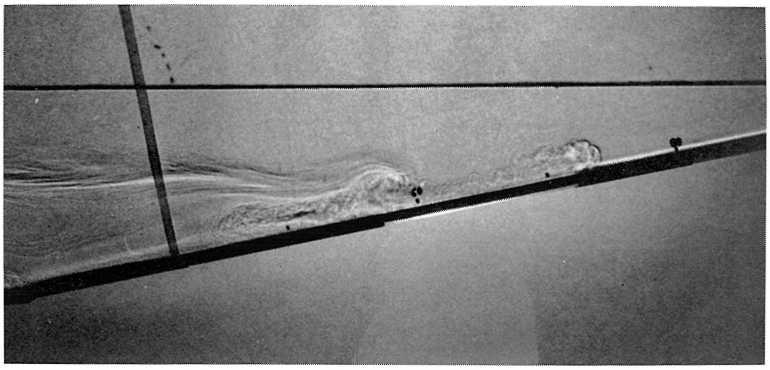
(d) $t=14$ s



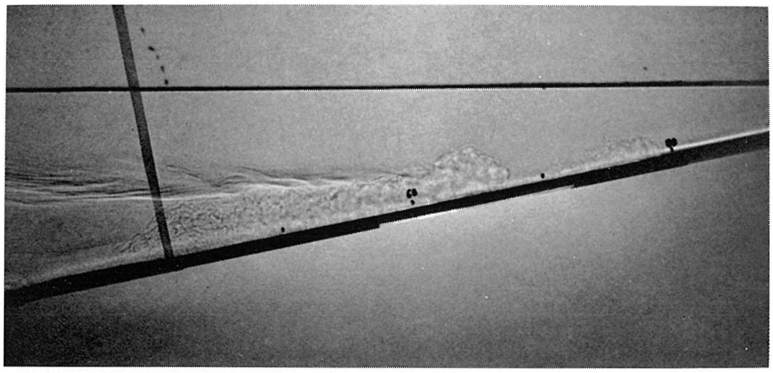
(e) $t=16$ s



(f) $t=17$ s



(g) $t=19$ s



(h) $t=22$ s

Fig. 7 Breaking bulge on a slope of 10° at $\Delta\rho/\rho_0 = 0.070$; scale unit in cm.

backwash vortex indicates that an internal backwash step and ripple marks may form on sloping sandy beds under the sea.

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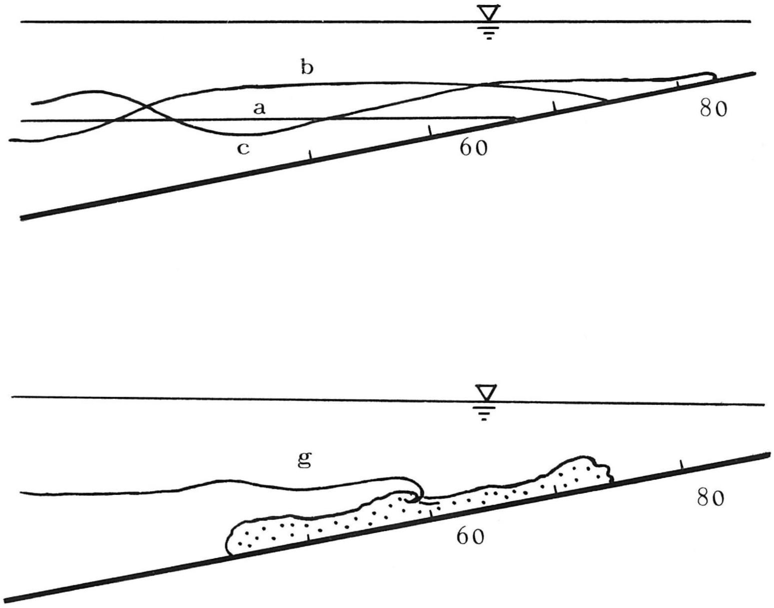
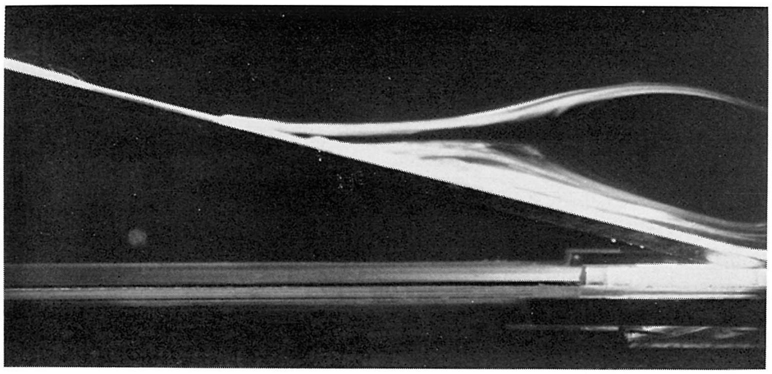
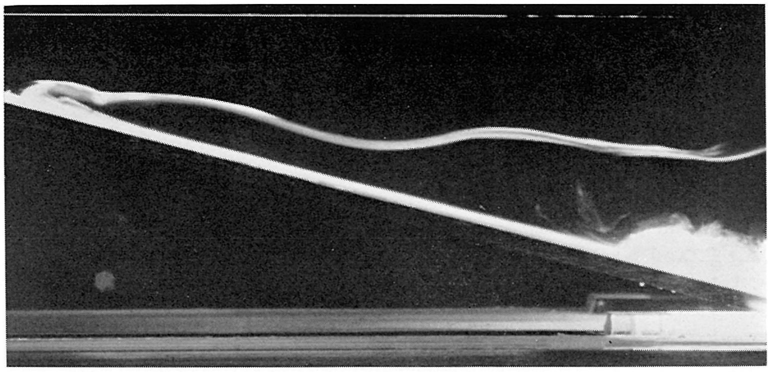


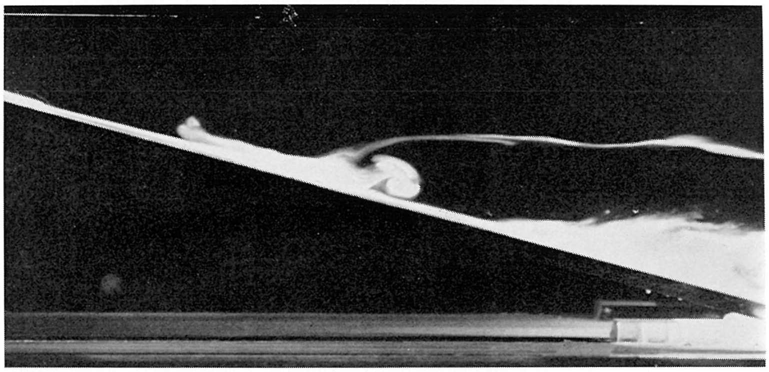
Fig. 8 Time-wise variation of boundary forms of the bulge shown in Fig. 7; unit in cm.



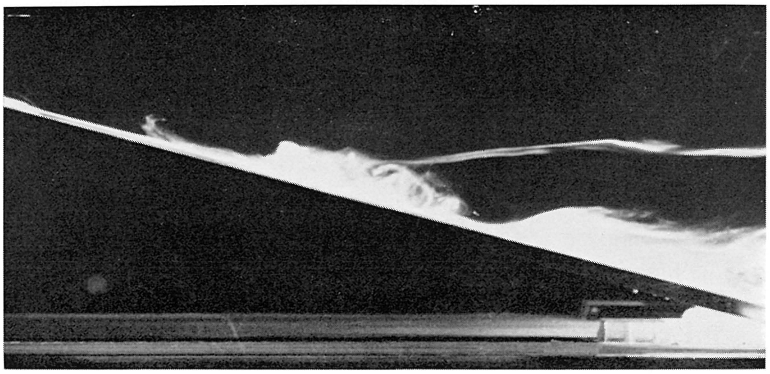
(a) $t=29$ s



(b) $t=38$ s



(c) $t=47$ s



(d) $t=50$ s

Fig. 9 Formation of an internal backwash vortex at a slope of 15.5° and $\Delta\rho/\rho_0=0.017$.

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