A THREE-DIMENSIONAL INSTABILITY OF THE SEPARATED FLOW OVER AN OSCILLATING STEP

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NOTE

A THREE-DIMENSIONAL INSTABILITY OF THE SEPARATED FLOW OVER AN OSCILLATING STEP

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A three-dimensional instability occurs in the flow induced over a 90° step, which oscillates harmonically in still water.

Key words: Three-dimensional flow instability, Oscillating step

1. Introduction

The formation of 'streaked flow' around a circular cylinder oscillating transversely in still water was reported in a preceding paper[1]. A typical pattern of the flow viewed obliquely from above is shown in Fig. 1. The streaks form due to the centrifugal instability of the flow along curved walls.

In this paper, it is shown that a similar instability occurs in the flow separated from the edge of an oscillating step.

2. Experimental method

Experiments were carried out using a $45 \times 30 \times 25$ cm glass-sided water tank, in which a plate installed with a 90° step as illustrated in Fig. 2 oscillated harmonically. Two kinds of models 30 cm in length and 25 cm in height were used; one was 1.0 and the other 1.2 cm in height (H). The amplitude ($d_0/2$) and frequency (f) of the oscillation were varied between 0.8 and 3.6 cm, and between 0.1 and 0.7 Hz, respectively. In Fig. 2, three slices of water illuminated with a 1 kW slide projector are indicated. Flow patterns in these planes were photographed with a camera, which was at rest with respect to the tank.

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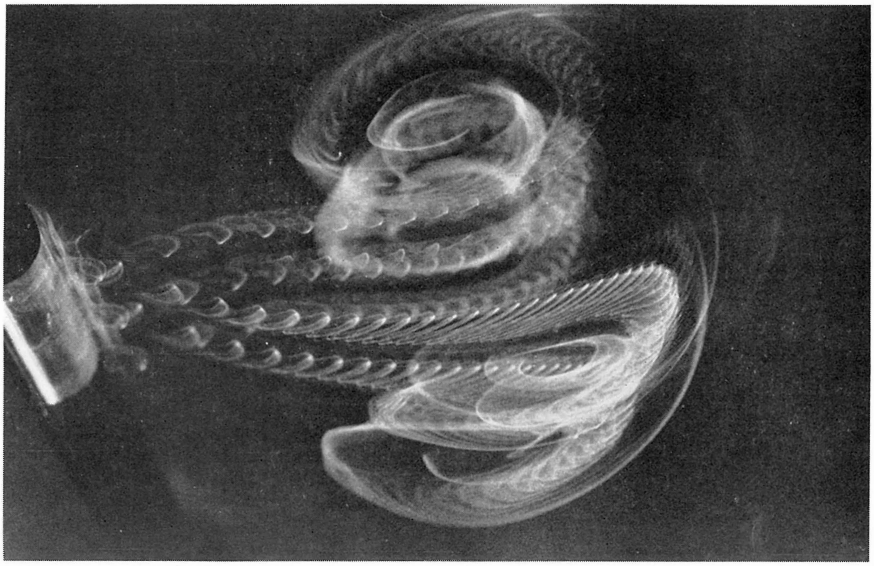


Fig. 1. Bird's-eye view of streaked flow around an oscillating cylinder. Oscillation direction is right and left. cylinder diameter = 2. 0 cm, f = 0. 24 Hz, d_0 = 1. 8 cm.

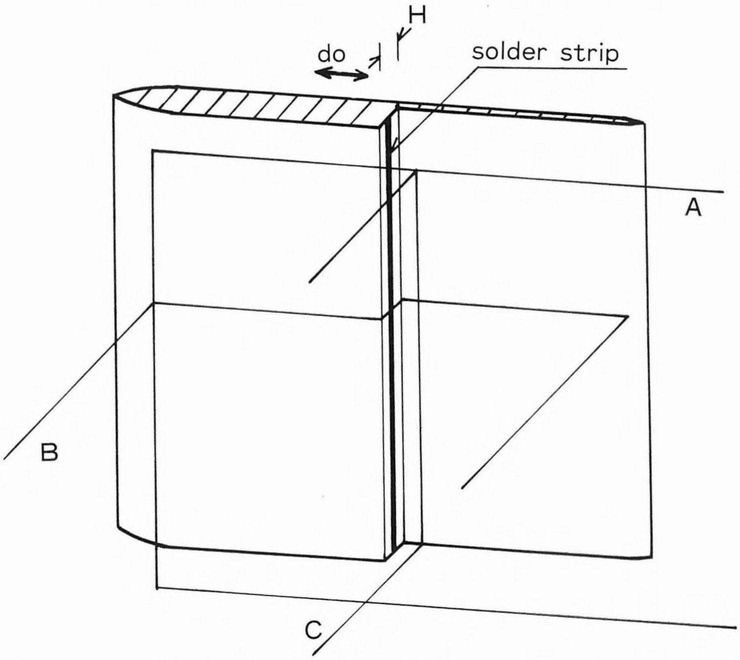
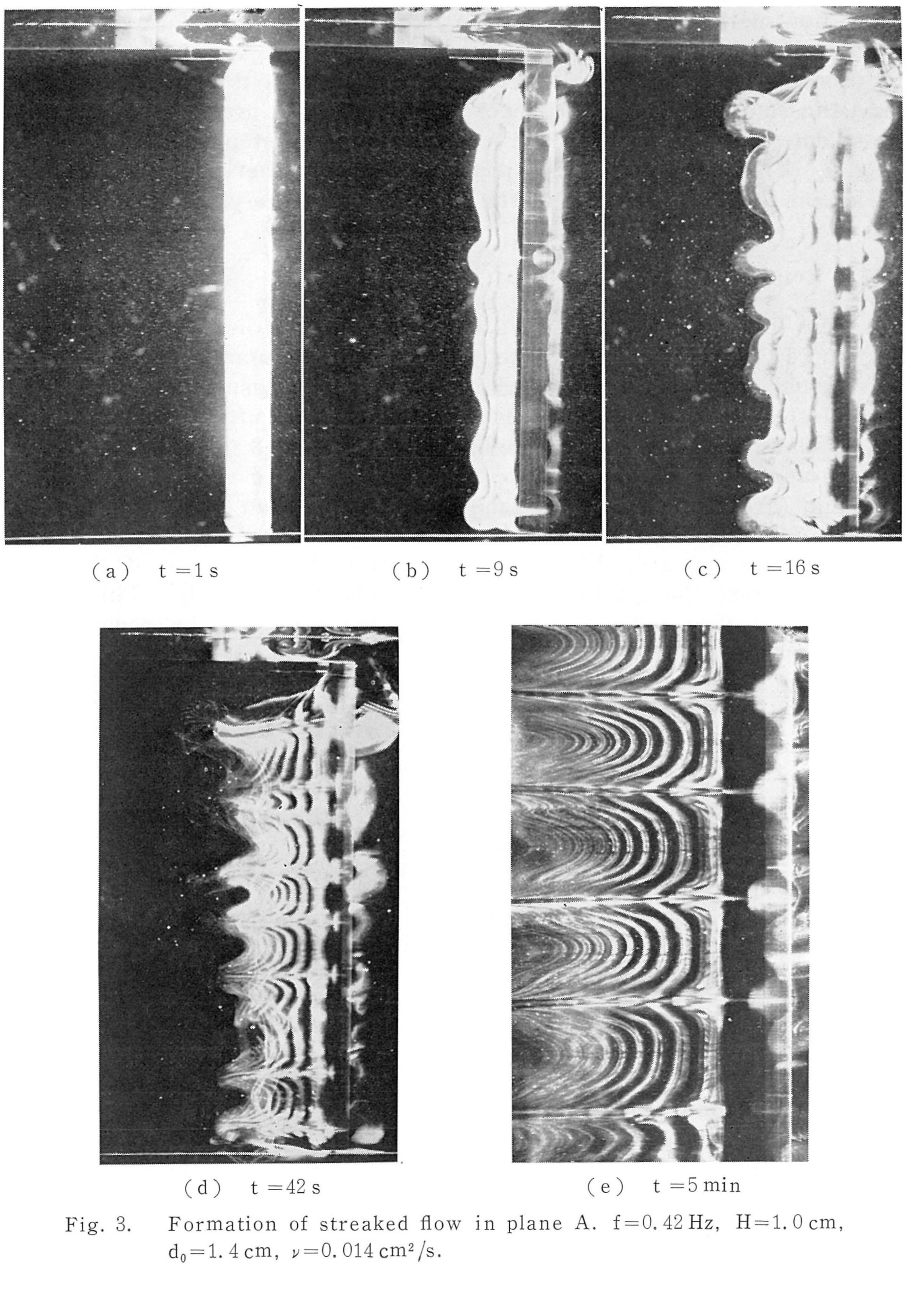


Fig. 2. Diagram of step model. Arrow indicates the oscillation direction. A, B, and C correspond to three different view planes in flow visualization.



(a) t = 1 s (b) t = 9 s (c) t = 16 s

(d) t = 42 s (e) t = 5 min

Fig. 3. Formation of streaked flow in plane A. $f=0.42$ Hz, $H=1.0$ cm, $d_0=1.4$ cm, $\nu=0.014$ cm^2/s.

The flow patterns were visualized by means of the electrolytic precipitation method and the aluminum flake method. The former method is described in a preceding paper[2) ; white smoke of a metallic compound is produced electrochemically from the surface of a thin strip of solder and the smoke is used as a tracer of flow. In the present experiments, a solder strip was put on the surface along the step line as shown in Fig. 2. The left side of the pictures displayed hereafter shows flow fields on the upper surface of the model, where the plate is thick.

3. Results

The time-wise variation of a flow over the step is shown in Figs. 3 (a) to (e), where t is the time passed from the start of oscillation of the model plate. The flow in plane A (Fig. 2) is visualized by means of the electrolytic precipitation method. Immediately after the step starts to oscillate, the flow is two-dimensional as in Fig. 3 (a). The flow becomes unstable with time and begins to be distorted wavily as in Figs.3 (b) and (c). The front of dye moves gradually from the lower surface to the upper, and a rhythmic pattern with a constant spacing (L) along the step line appears. Figure 3 (e) shows a close-up view of the flow pattern, where the spacing of about 2.5 cm is almost steady. This three-dimensional flow induced over an oscillating step may be regarded as a similar kind of streaked flow.

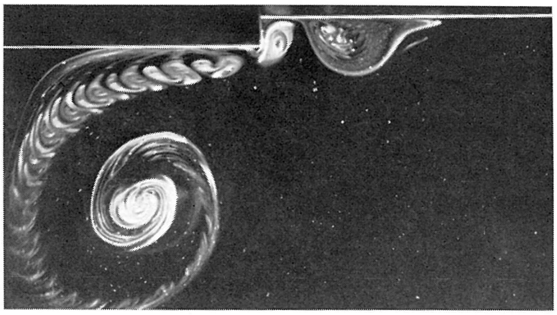
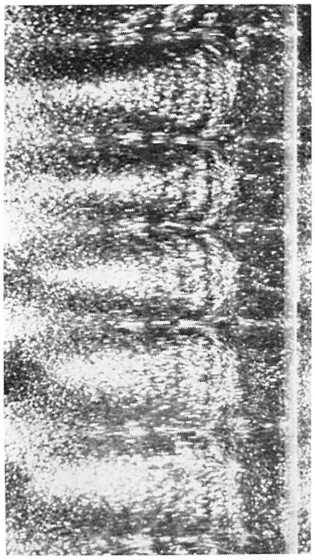


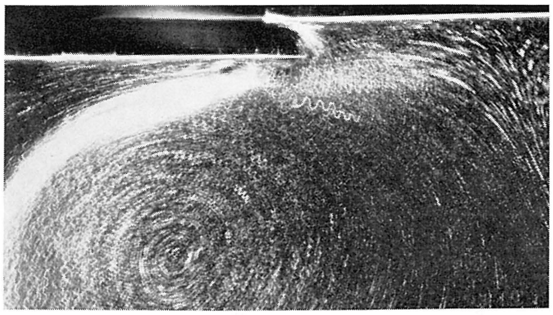
Fig. 4. Streaked flow in plane B. $f=0.40$ Hz, $H=1.0$ cm, $d_0=2.5$ cm, $\nu=0.014$ cm^2/s.

Figure 4 shows a flow pattern in plane B. A vortex separated from the step in every oscillation, and moved along the upper surface of the model. A group of the separated vortices formed a large swirl above the upper surface, and a closed vortical region also formed on the lower surface down the step, as shown in Fig. 4.

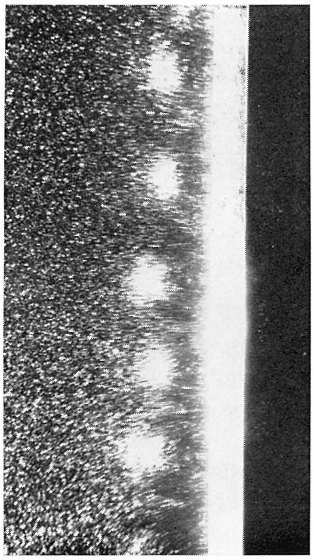
The steady streaked flows visualized with aluminum flakes are shown in Figs. 5 (a) to (c) : Figs. 5 (a), (b), and (c) show the flow patterns in



(a)



(b)



(c)

Fig. 5. Streaked flows visualized with aluminum flakes. $f=0.42$ Hz, $H=1.0$ cm, $d_0=1.4$ cm, $\nu=0.014$ cm^2/s.
(a) In plane A, (b) In plane B, (c) In plane C.

planes A, B, and C, respectively. Figure 5 (b) shows the flow to be compared with flow in Fig. 4.

In Fig. 6, the smallest and largest values of St at which the streaked flow forms clearly are plotted at d_0/H between 0.7 and 6.2: $St=H^2f/\nu$, ν being the kinematic viscosity of water. The symbol F indicates the

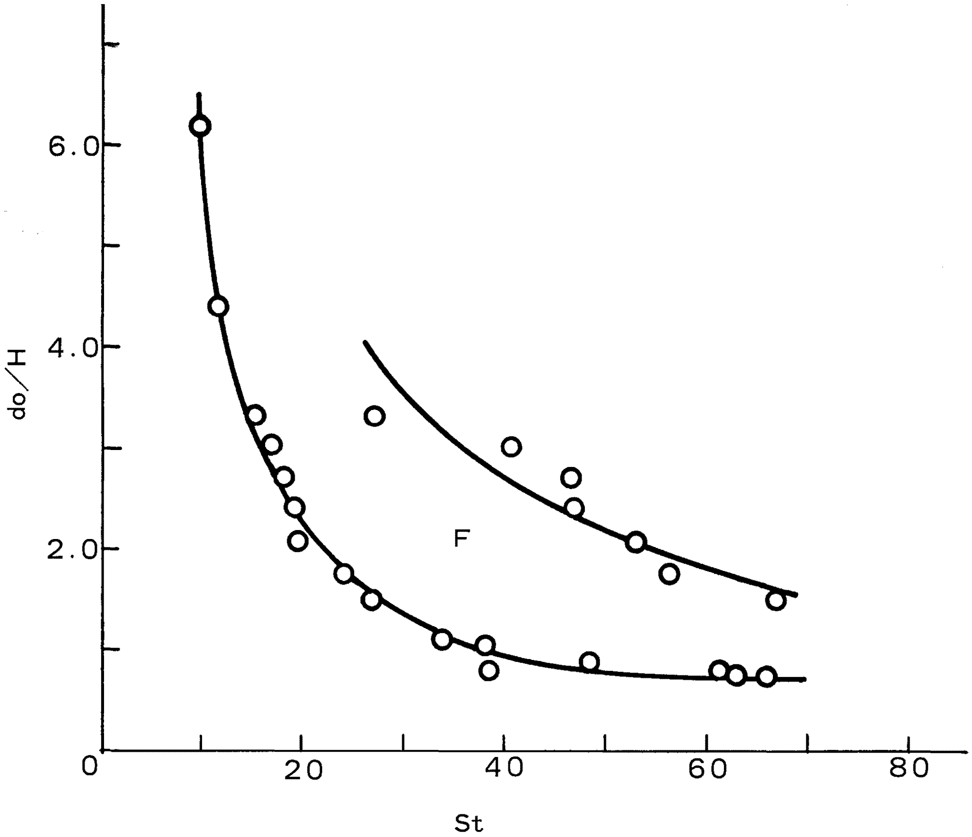


Fig. 6. Region (F) of streaked flow formation.

region of streaked flow formation, bounded by the upper and lower curves drawn through the plotted data. Below the lower curve separated flows are two-dimensional, and above the upper curve no clear streaked flow forms because of turbulence.

In Fig. 7, the measured values of L/H are plotted against St. Although the data for each d_0/H rather scatter, L/H decrease roughly with St similarly as in the case of an oscillating cylinder.

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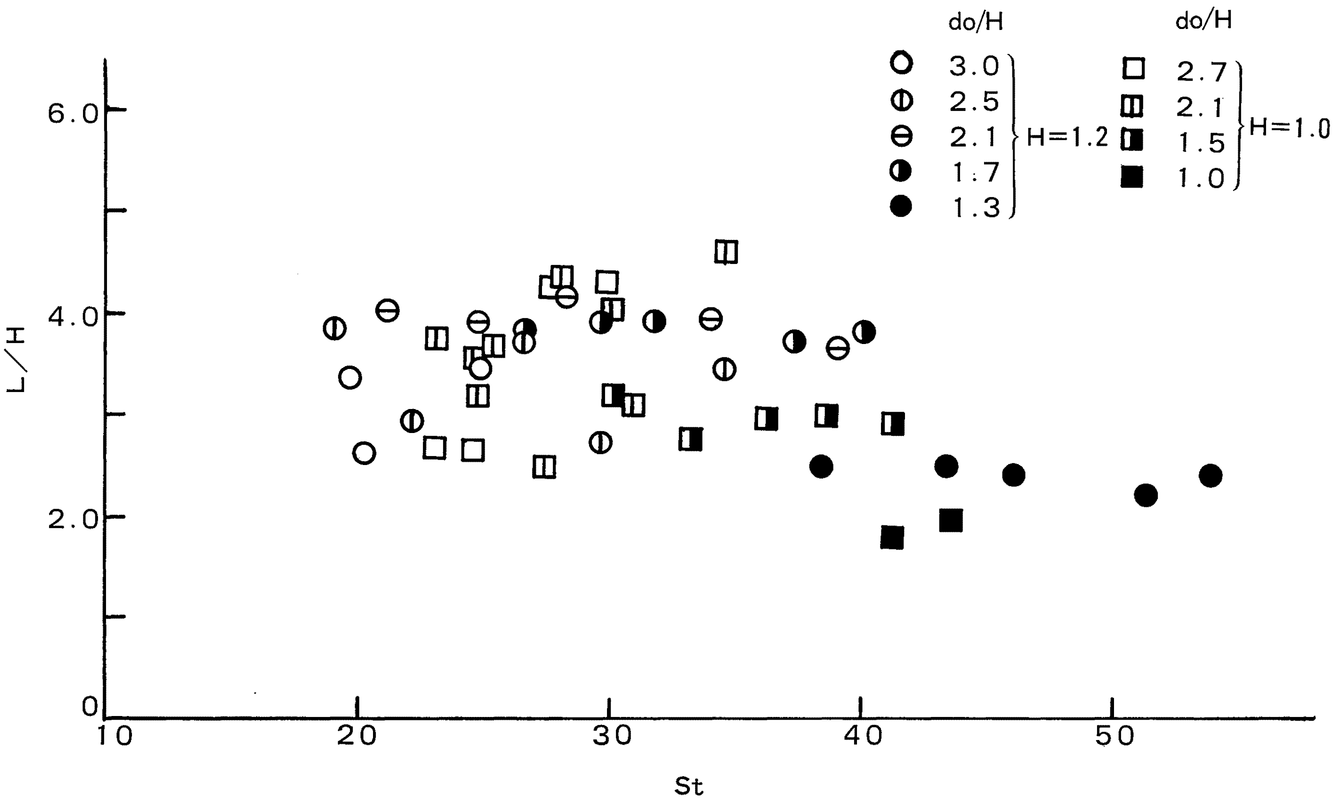

Fig. 7. St-dependence of streak spacing.

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