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WATER IMPINGEMENT ON A VERTICAL WALL DUE TO DISCONTINUITY DECAY ABOVE A DROP

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The paper reports experimental data on the height of water impingement on a vertical wall during wave reflection due to discontinuity decay above an even bottom and a bottom drop. It is shown that for a bore type wave with a roller in its head, propagating over finite-depth water, the impingement height is proportional to the initial difference in free-surface level. In the case of a "dry bottom" in the tail water, this is also true for other types of waves formed during discontinuity decay.

Key words: *experiment, open channel, bore type waves, vertical wall, impingement height.*

In hydraulics, decay of a boundary discontinuity (shortly, discontinuity decay) means the motion of a fluid with a free surface after removal of a vertical wall that previously separated two layers at rest [1, 2] (Fig. 1). Below, we consider only the height of water impingement on the vertical wall H averaged over the channel width. The impingement height is found as the distance from the channel bottom to the margin of the wet zone on the vertical wall. We note that for large values of the initial level difference P, part of the liquid separates from the wall and rises up to form individual jets or drops. This process is ignored in determining H.

This study is a continuation of [3, 4], in which liquid impingement on a vertical wall was studied experimentally for the case of discontinuity decay above an even horizontal bottom. In the present paper, we consider a more general formulation of the problem, in which the horizontal bottom of a rectangular channel has a drop (sudden downstream lowering of the bottom) of height b, above which there is an initial difference (discontinuity) in free-surface level. For comparison, we also studied discontinuity decay above an even bottom ($b = 0$). Previous experimental results are reviewed in [3, 4]. Wave impingement on a vertical wall due to short-duration removal of a plate above an even bottom was investigated in the experiments of [5, 6], where emphasis was placed on impingement of solitary waves. In [3, 4] and in the present paper, waves of the type of a moving hydraulic jump (bore)were considered. As is shown in [3], the picture of smooth undular bores and solitary waves impinging on a vertical wall have much in common.

The solution of the problem of discontinuity decay above an even bottom is used to analyze consequences of dam break [1, 7], and discontinuity decay above a drop is of interest for analysis of accidents at ship locks [8].

Experiments were performed in a rectangular channel of width $B = 20.2$ cm. A drop of height b was at distance $l = 1.93$ m from the right closed end of the channel (Fig. 1). The left open end of the channel was attached to a pool of length 3.3 m and width 1 m located at distance $l_1 = 2.27$ m from the drop. Thus, we simulated conditions typical of a ship lock with an outport having a large free-surface area. Below, we consider only those time intervals from the beginning of the discontinuity decay in which the wave reflected from the free end of the channel has not yet reached the specified channel cross section.

The depth of the fluid at rest before the drop h_- was set by a flat shield placed above the drop (Fig. 1). The depth of the fluid at rest behind the drop is denoted by h_+. We consider the cases $h_+ \neq 0$ and $h_+ = 0$. For $h_+ = 0$, we use the term "dry bottom." The difference in the free-surface levels $P = h_- + b - h_+$ characterizes the initial energy of the fluid. At time $t = 0$, the shield was removed manually from the channel. The law of motion of this shield was recorded by a slide-wire gauge. Measurements were performed only if the duration of shield removal

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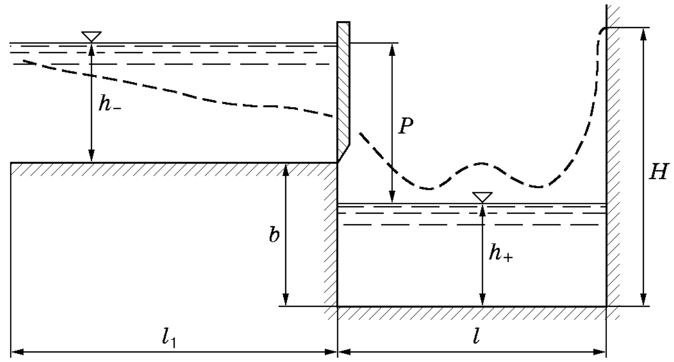

Fig. 1. Diagram of the experiment.

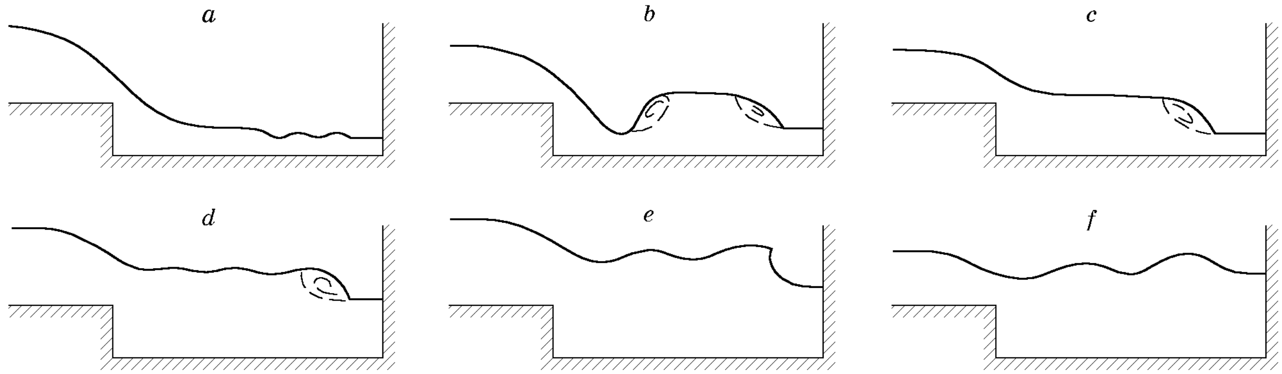

Fig. 2. Typical wave profiles in the vicinity of the wall.

did not exceed 0.05 sec with the shortest time of wave propagation from the drop to the vertical wall being 1.3 sec in the experiments.

In the vicinity of the closed end of the channel there was a removable vertical Plexiglas plate coated with a tooth powder. The waves reflected from the plate washed this powder away, so that we could measure the value of H by the distinct boundary between the wet and dry areas. For large P, the height of the wet zone on the plate changed over the channel width [4, 6]. The values of H given below are averaged over the channel width. In the experiments, the parameters h_-, h_+, and b were varied, and the parameters B, l, and l_1 were constant.

The impingement height depends on the type of incident waves. Figure 2 shows typical experimental free-surface profiles recorded downstream of the drop before wave reflection from the closed channel end. For the profile in Fig. 2a, the flow incident on the wall is in the supercritical state (in a fixed coordinate system). The profile in Fig. 2b has two classical downstream moving hydraulic jumps with rollers in their heads, and the propagation speed of the first jump is higher than that of the second one. The profile presented in Fig. 2c has only one classical moving hydraulic jump. The profile in Fig. 2d shows relatively weak undulations behind the roller of a classical bore. In the free-surface profile shown in Fig. 2e, one can see prominent undulations but the head roller is also retained. This wave can be called an undular bore with a breaking front. The profile in Fig. 2f corresponds to a wave that can be called a smooth undular bore.

The diagrams given in Fig. 2 do not exhaust the possible free-surface profiles in the problem considered even with no superposition of direct and reflected waves. For example, for sufficiently large l, l_1, and P, one can sequentially observe all the profiles shown above and also the solitary and linear waves formed in the final stages of degeneration of an undular bore [9]. Moreover, at the stage of transition from a classical bore to a smooth undular bore, we can distinguish more transitional characteristic profiles than is shown in Fig. 2d and e [10]. Calculations using Saint Venant's equations (see, for example, [2]) yield only the first three bore shapes (Fig.2a, b, and c). To describe the other profiles, one need to use mathematical models that take into account the deviation from hydrostatic pressure distribution over depth and mixing due to wave breaking.

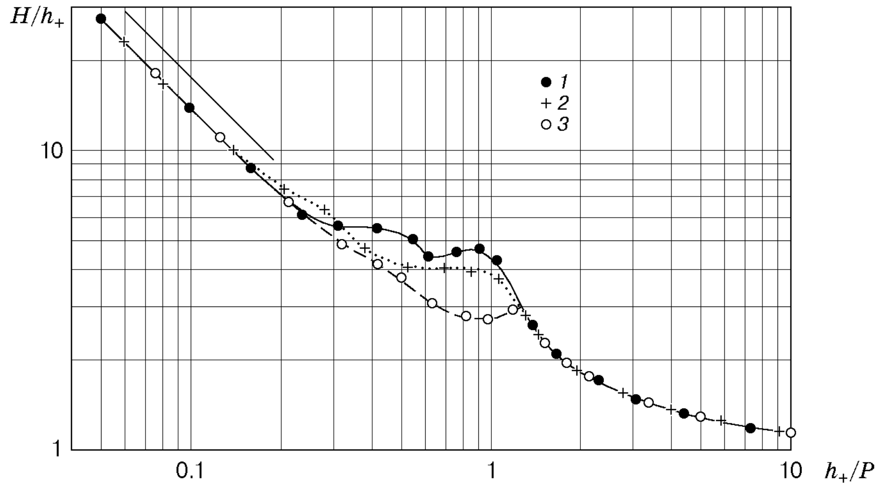

Fig. 3. Impingement due to discontinuity decay above an even bottom ($b/l = 0$) for $h_-/l = 0.11$ (1), 0.079 (2), and 0.053 (3).

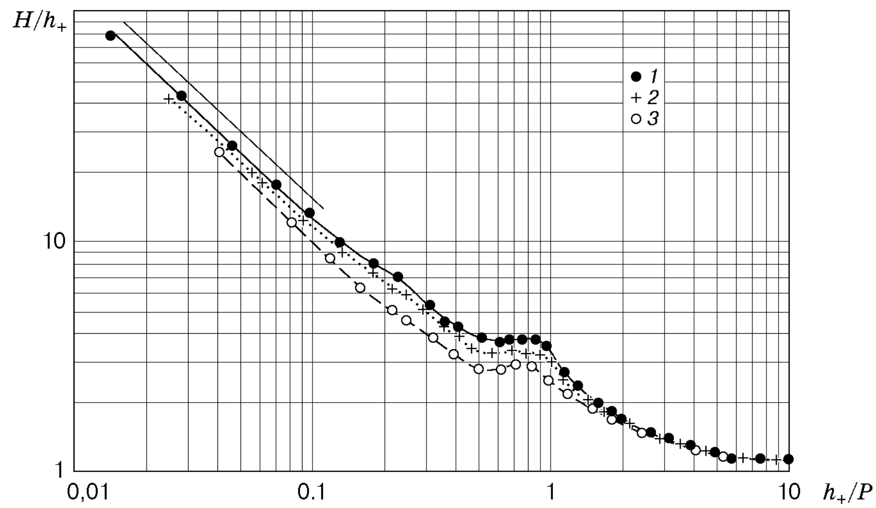

Fig. 4. Impingement due to discontinuity decay above a drop of height $b/l = 0.026$ for $h_-/l = 0.080$ (1), 0.062 (2), and 0.039 (3).

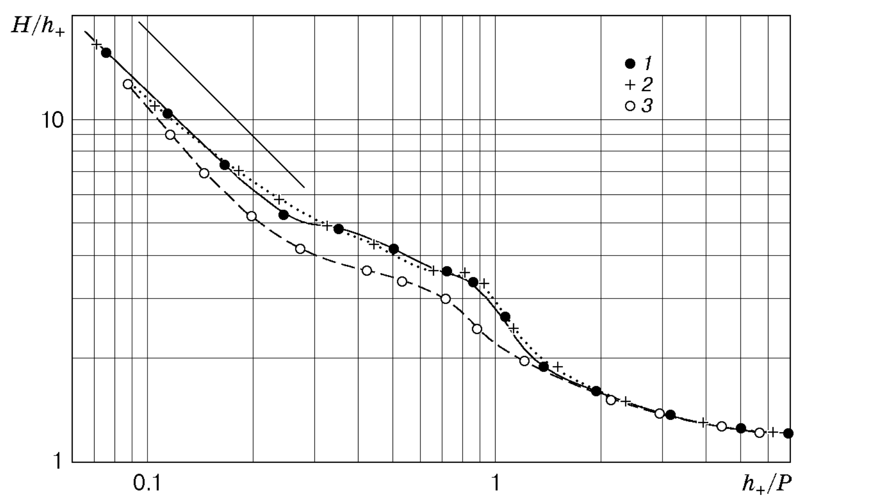

Fig. 5. Impingement due to discontinuity decay above a drop of height $b/l = 0.037$ for $h_-/l = 0.080$ (1), 0.062 (2), 0.039 (3).

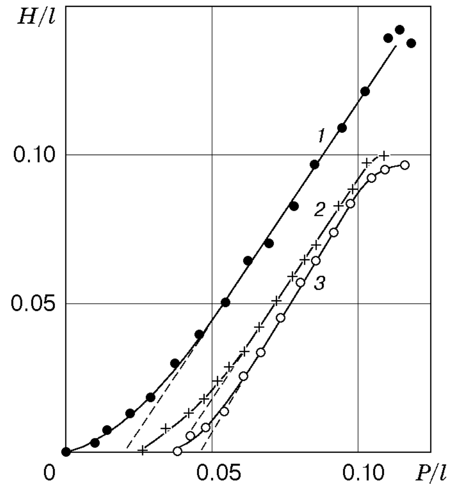

Fig. 6. Impingement due to wave propagation over a dry bottom for $b/l = 0$, $a = 1.45$, and $c = 0.028$ (1), $b/l = 0.026$, $a = 1.50$, and $c = 0.057$ (2), and $b/l = 0.036$, $a = 1.61$, and $c = 0.074$ (3).

During reflection of a smooth undular bore (Fig. 2f), the height of the wet area did not change over the channel width. In the case of reflection of a classical bore with a head roller (Fig. 2b and c), the boundary between the wet and dry zones was irregular but jets did not rise up into the air. In the case of transitional shapes (Fig. 2d and e), the boundary was even more irregular, and jets separated from the wall. Other conditions being equal, the greatest height of impingement H was observed in the case where breaking of a smooth undular bore began when its leading edge approached the vertical wall (Fig. 2e).

Figure 3 gives a curve of the relative impingement H/h_+ versus the depth behind the drop h_+/P if $h_+ \neq 0$ for the case of discontinuity decay above an even bottom ($b = 0$). As follows from Fig. 3, for large and small values of h_+/P, the curve considered is universal in the parameter h_-/l. For intermediate values of h_-/l, this universality is violated because of the shape of incident waves. For small h_+/P, the wave had the shape of a classical bore with a head roller. In this case, $H/h_+ \sim (h_+/P)^{-1}$ (solid straight line in Figs. 3–5). For large h_+/P, this universality takes place if the incident wave has the shape of a smooth undular bore. For other wave patterns shown in Fig. 2, the impingement height in Fig. 3 depends on all parameters.

Figures 4 and 5 give experimental data on impingement due to discontinuity decay above a drop for two values of b/l and $h_+ \neq 0$. In this case, the curve of H/h_+ versus h_+/P is similar to that for discontinuity decay above an even bottom. However, additional energy dissipation occurs behind the drop, which grows with increase in b/P and decrease in h_+/P. As a result, other conditions being equal, the region of existence of the waves shown in Fig. 2d and e is shifted toward small values of h_+/P, and the impingement height decreases.

Figure 6 shows results of experiments in which a wave propagated over a dry bottom ($h_+ = 0$). One can see that both in the case of an even bottom and in the case of a drop there exists a range of parameters in which the dependence of H on P is linear (dashed curves in Fig. 6):

$$H/l = aP/l - c.$$

The coefficients a and c depend on the difference in free-surface levels, the drop height, and the distance from the drop to the wall (Fig. 6).

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