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Dead zone area at the downstream flow of barrages

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Abstract Flow separation is a natural phenomenon encountered at some cases downstream of barrages. The main flow is divided into current and dead zone flows. The percentage area of dead zone flow must be taken into consideration downstream of barrages, due to its negative effect on flow characteristics. Experimental studies were conducted in the Hydraulic Research Institute (HRI), on a physical regulator model with five vents. Theoretically the separation zone is described as a part of an ellipse which is practically verified by plotting velocity vectors. The results show that the percentage area of dead zone to the area through length of separation depends mainly on the expansion ratio [channel width to width of opened vents], with maximum value of 81% for operated side gates. A statistical analysis was derived, to predict the percentage area of dead zone flow to the area through length of separation.

1. Introduction

In Egypt, multi-vent regulators are widely used to control the flow and discharge in the main irrigation canals and across the River Nile. During maintenance programs, some vents may be closed and others are kept open. If one or more side vents are opened (or closed) and the vents on the other side are closed (or opened), it is a case of asymmetric operation. The main flow body is divided into current and dead zone flows. The area of dead zone flow has a negative effect on flow characteristics downstream of multi-vent regulators, because the area of reversal flow increases causing possible damage to the bed and sides downstream of the channel. Also, the water flow through a limited width and the velocity of forward flow increases, causing high turbulence downstream hydraulic structures can progressively damage the bed protection, eventually leading to the failure of the hydraulic structures.

In order to investigate the area of dead zone flow downstream of multi-vent regulators, an extensive experimental work has been conducted on a five vent regulator physical model. The operating system includes openings of four, three, two, and one side vent. The velocity vectors downstream of the piers were measured by making a mesh of points to investigate the zone of dead flow, and the length of separation.

Previous investigations on rigid hydraulics of abruptly enlarged stilling basins proved that the flow patterns in such basins are asymmetric. Graber [1] reported some studies and presented an explanation of the asymmetric behavior of the subcritical flow in symmetric sudden expansion. He also presented a predictive method that agreed with the experimental observations and extended the predictive method theoretically to correct measures up to a Froude number of 1.5. Graber [2]

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Nomenclature

Symbols

A_R%	the percentage area of reverse flow through the length of separation (–)
A%	the percentage area of dead zone flow through the length of separation (–)
A_D	the dead zone area of flow (L^2)
A_T	the total area of flow through the length of separation ($A_T = B * L$) (L^2)
B	width of channel (L)
b	width of the vent (L)
b_t	width of the opened vents ($b_t = n * b$) (L)
e	expansion ratio, $= B/b_t$ (–)
F_1	initial Froude number (–)
Fg	Froude number under gates (–)
G	gate opening (L)
H_U	upstream water depth (L)
L	the length of separation (L)
n	the number of opened vents (–)
Q	the total discharge ($L^3\,T^{-1}$)
R	the radius of separation line between forward flow and reverse flow at any plane (L)
R_n	Reynolds number
V_X	velocity component in the longitudinal direction ($L\,T^{-1}$)
V_Y	Velocity component in the lateral direction ($L\,T^{-1}$)
W	the max. width of dead zone (L)
X	distance from pier (L)
Y_1	depth of flow at the Vena Contracta (L)
Y_3	backup water depth just downstream of the gate (L)
Y_t	tail water depth at the end of the submerged jump (L)
Y	depth of water (L)
Z	depth of water plane from water surface (L)

Abbreviations

R^2	coefficient of multiple determination
S.E.E	Standard error of estimate

presented an explanation for asymmetric flow patterns of the supercritical flow in symmetric sudden expansion, in which the hydraulic jump is one of the flow features. The explanation was shown to be in accordance with the available observations.

Mehta [3] analyzed flow patterns for recirculating flows in sudden two-dimensional expansions by numerical approaches and experimental studies. Analytical results for low expansion ratio of 1.25 are in agreement with experimental findings. For larger expansion ratios, experimental results reveal that the flow patterns are asymmetric and unstable, because turbulence decays at faster rate after the points of reattachment, and flow attains symmetric conditions earlier.

Seemly few studies exist for the flow separation area downstream of barrages. Ramamurthy et al. [4] studied the separation of flow in diversion channels that cause damages in the bed and sides of the downstream channels. They made an experimental work on a flume, constructed from precast concrete slabs with and without a hump set in the transition section. They realized that the use of a simple hump reduced the flow separation and limited the area in which the reverse flow occurs. This decrease in reversal flow contributes to the reduction of possible damage to the bed and sides downstream of the channels.

Frizzell and Werth [5] perform a physical model study to evaluate the separation zones in such hydraulic phenomena. The physical model was used to validate analytical method of the opposing flow condition. Results show positive accord between analytical method and physical model. The validated analytical method approach can be used to predict the maximum width of the separation zone. An analytical tool was presented to assess the potential for hydraulic jumps or choked flow conditions in water distribution applications.

Herbrand [6] indicated that the dimensionless length of separation may be considered as nearly independent of the longitudinal coordinate x, while it depends on the initial Froude number F_1. Herbrand introduced a formula for the dimensionless length of separation (W/L) which occurs for an abrupt 90° enlargement stilling basin as follows:

$$\frac{W}{L} = \frac{1.5}{F_1}. \tag{1}$$

where W is the maximum width of dead zone, L is the length of separation zone, and F_1 is the inflow Froude number.

Abdel-Aal et al. [7] measured experimentally the separation of flow in a radial stilling basin at the downstream of multi-vent regulators. The measured dimensionless length of separation (W/L) was plotted against the initial Froude number F_1 for different operating scenarios and a statistical formula predicting the dimensionless length of separation (W/L) was introduced as follows:

$$\frac{W}{L} = -0.078 + \frac{0.322}{e} + 0.036F_1 \tag{2}$$

where e is the expansion ratio.

Abdel-Aal et al. [8] studied experimentally the separation of flow at a sudden expanding stilling basin at the downstream multi-vent regulators. They considered that the plane of separation is the smooth solid boundary between the reverse and current flows, vertically from the water surface to the bed, and as a part of circle:

$$\left(R = \frac{L^2}{2W} + \frac{W}{2}\right) \tag{3}$$

where R represents the radius of separation line between forward flow and reverse flow for any plane. The hypothesis of the separation zone as a part of circle is particularly verified by plotting velocity vectors. The dimensionless length of separation (W/L) depends on the expansion ratio (e) and the initial Froude number (F_1), while the effect of submergence ratio (S) can be neglected. A statistical form was developed based on the multiple linear regression to predict the dimensionless length of separation, as follows: