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Simplified procedure for determining of drop and stilling basin invert elevations

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KEYWORDS

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Direct solutions

Abstract Drops are used to effectively dissipate the surplus energy of the water flow. A closed conduit drop conveys water and stills it at its downstream. I-type pipe drop is one kind of the closed conduit drops which is used in irrigation networks as a typical hydraulic structure. Sump elevation is an important design parameter for I-type pipe drop. Similarly, in supercritical flow structures, such as open channel chutes, determination of stilling basin invert elevation is very important. At present, these key design parameters are determined by the momentum and energy equations using tedious trial-and-error procedure. In this study, square conduit drop, pipe drop, and rectangular stilling basin are considered, and three explicit equations have been developed by (multiple) nonlinear regression technique to determine the sump and stilling basin invert elevations. Being very simple and accurate, these equations can be easily used to design the closed conduit drops and stilling basins by hydraulic engineers.

1. Introduction

A pipe drop conveys water from a higher point to a lower one. The height of the drop is considered between 1 and about 5 m [1]. This structure dissipates the excess energy and stills the water after reaching the lower elevation. I-type and II-type pipe drops are two general types of closed conduit drops which are used in irrigation networks as typical hydraulic structures. In this research, only the I-type pipe drop is considered. The I-type pipe drop (Fig. 1) is a practical and economical drop and is used as an inline canal structure where the possibility of clogging is minimal [1]. To dissipate the excess energy from the supercritical flow in the sloped part of the structure, stilling is completed by providing a depressed section of pipe near the outlet end.

Similarly, open channel chutes are used to convey water from a higher elevation to a lower elevation (Fig. 2). In a chute, water flows down the steep slope section at a velocity greater than the critical velocity. The abrupt change in slope, forces the water into a hydraulic jump, and thus, energy is dissipated [1]. The stilling basin is usually proportioned to contain the jump. For a stilling basin to operate properly, the Froude number should be between 4.5 and 15 [1]. It is not the purpose of this study to describe in detail the components and design

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Notation

A^*	non-dimensional flow area ($=A/D^2$)
A	flow area
B	width and height of the square conduit
D	pipe diameter
g	gravitational acceleration
Q_*	non-dimensional discharge ($=Q^2/gD^5$ or Q^2/gB^5)
Q	discharge
q	discharge intensity
V	flow velocity
V_p	full pipe velocity
y_1	prejump flow depth or supercritical sequent depth
y_2	postjump flow depth or subcritical sequent depth
y_c	depth of the centroid of the flow area from the water surface
y_{cr}	critical flow depth

Greek symbols

ξ	non-dimensional depth for chute, barrage or weir ($=y/y_{cr}$)
η	non-dimensional depth for conduit drop ($=y/D$ or y/B)
λ	non-dimensional head loss of the jump for chute, barrage or weir ($=\Delta E/y_{cr}$)
ε	non-dimensional head loss of the jump for conduit drop ($=\Delta E/D$ or $\Delta E/B$)
θ	water surface angle
ΔE	deference of energy grade line of the canal at upstream and downstream ends of the structure
ΔE_j	head loss of the jump

Subscripts

1, 2 and p	denote prejump, postjump and full pipe characteristics respectively
*	makes dimensionless

considerations for the conduit drops and rectangular stilling basins. The reader is referred to [1] for more information about various components of these structures. Design of a hydraulic structure such as a drop or stilling basin involves the hydraulic and structural designs. Both aspects of the design procedure must complement each other for the structure to be efficient. In this research, it is only considered the hydraulic design.

Determination of sump and stilling basin invert elevations requires knowledge of various elements of hydraulic jump with known values of "*discharge*" and "*head loss*" in the jump. In designing the conduit drop and open channel chute, the head which should be dissipated (head loss) is equal to the difference of the energy grade line (EGL) elevations at the upstream and the downstream sections and has to be known before jump calculations. Sump and stilling basin invert elevation can be fixed only after postjump depth determination.

USBR [1] and Chow [2] have given various graphs, equations, and design procedures; however, none of these procedures give the values of postjump depth directly for the given values of "*discharge*" and "*head loss*." Swamee et al. [3] obtained a direct solution of sequent depths for the design of a stilling basin downstream of a barrage. These equations are very simple for handy calculations and can be used by hydraulic engineers easily.

Chaurasia [4] considered an explicit equation for postjump depth by multiple nonlinear regression analysis with a percentage error of 5.9%. Chaurasia's work [4] is a very similar version of Swamee and Prasad [5] as evident from [6,7].

Swamee and Rathie [8] presented exact equations for sequent depths in a stilling basin of a barrage or weir in terms of infinite series using Lagrange's theorem. These solutions are not very simple for handy calculations.

In spite of many investigations on the explicit sequent depths equations in a stilling basin of a barrage, from the above literature review, it is revealed that there is no direct solution to determine the sump invert elevation. At present, this parameter is determined using tedious trial-and-error procedure. In this research using specific force and specific energy equations, direct equations are presented for this design parameter. The solutions are then illustrated with the help of numerical examples.

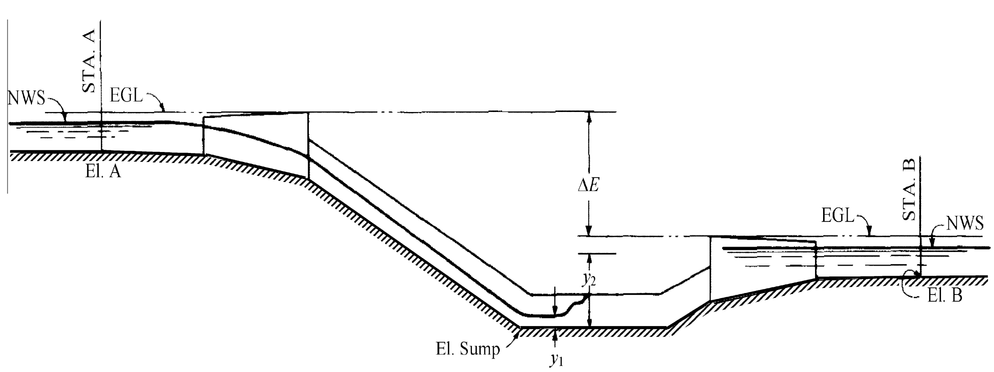

Figure 1 I-type pipe drop.