Journal of Water and Soil
Vol. 29, No. 5, Nov.-Dec. 2015, p. 1105-1116

نشریه آب و خاک (علوم و صنایع کشاورزی)
جلد ۲۹، شماره ۵، آذر – دی ۱۳۹۴، ص. ۱۱۱۶-۱۱۰۵

The Free Overfall in Circular Sections with Different Flat Base in Supercritical and Subcritical Flow Regimes

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Received:10-02-2014
Accepted:03-05-2015

Introduction: A free overfall offers a simple device for flow discharge measuring by a single measurement of depth at the end of the channel y_b which is known as the end depth or brink depth. When the bottom of a channel drops suddenly, the flow separates from sharp edge of the brink and the pressure distribution is not hydrostatic because of the curvature of the flow. In channels with subcritical flow regime, control section occurs at the upstream with a critical depth (y_c). Although pressure distribution at the critical depth is hydrostatic, the location of the critical depth can vary with respect to the discharge value. So, the end depth at brink is offered to estimate the discharge. A unique relationship between the brink depth (y_b) and critical depth (y_c), known as end-depth ratio (EDR = y_b/y_c), exist. Since a relationship between the discharge and critical depth exists, the discharge can ultimately be related to y_b. However, when the approaching flow is supercritical, critical section does not exist. Therefore, the discharge will be a function of end depth and channel longitudinal slope.

In current study, an analytical model is presented for a circular free overfall with different flat base height in subcritical and supercritical flow regimes. The flow over a drop in a free overfall is simulated by applying the energy to calculate the EDR and end depth-discharge (EDD) relationship.

End-depth-discharge relationship: The flow of a free overfall in a channel can be assumed that is similar to the flow over a sharp-crested weir by taking weir height equal to zero. It is assumed that pressure at the end section is atmospheric, and also streamlines at the end section are parallel. To account for the curvature of streamlines, the deflection of jet due to gravity, the coefficient of contraction, C_c, is considered. At a short distance upstream the end section, the pressure is hydrostatic. By applying the energy equation between end section and control section which is at upstream the end section, the flow depth at the end of the channel y_b in terms of depth at the control section can be determined.

Subcritical flow regime: In this case, the approach flow to the brink is subcritical for negative, zero and mild bed slopes with critical depth at the control section. Using the definition of the Froude number at critical depth, the discharge can be determined. As the explicit relationship between discharge and depth at the brink don't exist, a relationship should be presented through regression analysis between discharge and y_b using the different values of y_c over the practical range of 0.01 to 0.84. In this study, below explicit equation is presented for computing Q*(dimensionless discharge) in terms of $\hat{y}_b$ ($\hat{y} = y/d$):

$$Q^* = \left([1.1 - 1.945(w^*)^{4.9}](\sin^{-1}\hat{y}_b)^{0.4275} + [2.1(w^*)^{5.4} + 0.104]\hat{y}_b - 0.003\right)^{3.4}$$

Where d is channel diameter, $\hat{w} = w/d$ is the ratio of bottom elevation to the channel diameter and $w^* = 0.7 - \hat{w}$. This equation can be used for different values of w^* over the practical range of 0.06–0.6.

Supercritical flow regime: A critical flow occurs upstream of the free overfall under the subcritical approach flow. However, no such critical flow occurs in the vicinity of the overfall under supercritical flow regime. Therefore, the Manning equation for known value of channel bed slope and Manning's coefficient is exercised to derive the discharge relationship under the supercritical flow regime. Since an explicit equation for discharge in term of y_b is impossible, a direct graphical solution for discharge for known end depth, channel bed slope, and ratio of bottom elevation has been provided for supercritical flow regime.

Conclusion: The free overfall in a circular channel with flat base has been simulated by the flow over a sharp-crested weir to calculate the end-depth ratio. This method also eliminates the need of an empirical pressure coefficient. The method estimates the discharge from the known end-depth. In subcritical flows, the EDR has been related to the critical-depth. On the other hand, in supercritical flows, the end-depth has been expressed as a function of the longitudinal slope of the channel using the Manning equation. The mathematical solutions allow

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estimation of discharge from the known end-depth in subcritical and supercritical flows. The comparisons of the experimental data with this model have been satisfactory for subcritical flows and acceptable for supercritical flows.

Keywords: Circular overfall, End-depth, Flow measurement, Non-hydrostatic pressure distribution, Numerical methods