Flow Measurement and Instrumentation 28 (2012) 16–21

Contents lists available at SciVerse ScienceDirect

Flow Measurement and Instrumentation

journal homepage: www.elsevier.com/locate/flowmeasinst

Direct solutions for normal and critical depths in standard city-gate sections

Ali R. Vatankhah

Department of Irrigation and Reclamation Engineering, University College of Agriculture and Natural Resources, University of Tehran, P.O. Box 4111, Karaj 31587-77871, Iran

ARTICLE INFO

Article history:
Received 19 March 2012
Received in revised form
4 July 2012
Accepted 22 July 2012
Available online 14 August 2012

Keywords:
Critical and normal depths
Standard city-gate sections
Explicit equations

ABSTRACT

Critical and normal depths are important parameters for computing gradually varied flow and for the design, operation, and maintenance of open channels. For many channel sections, the governing equations for critical and normal depths are implicit and no analytical solutions exist. Thus various approximate equations with various degrees of error have been developed for these sections. No explicit equations exist for critical and normal depths of the standard city-gate cross-sections for entire practical range of the water depth. City-gate sections are one of the commonly used cross-sections for water conveyance tunnels. Standard city-gate cross-sections are also used for water conveyance in irrigation and drainage systems. This study proposes explicit equations for critical and normal depths of standard city-gate cross-sections. The proposed equations are simple and valid for entire practical range of the water depth and have maximum relative error less than 0.13% and thus should be useful tools for evaluation and design of the standard city-gate cross-sections.

1. Introduction

Computation of critical and normal depths is an important task in hydraulic design of open channels. These depths are very important for understanding the flow characteristics in open channels. The channels of first kind in which top-width of water surface increases or is constant with flow depth will have a unique normal depth associated with each discharge. Many researchers have developed explicit solutions to compute normal and critical depths in channels of the first kind (like trapezoidal, rectangular and triangular). Channels with a closing top-width are considered [1] as channels of the second kind. Top surface width decreases with flow depth in these types of channels in some cases and two normal flow depths are possible for any particular discharge in some cases of flow. Channels with circular, egg-shaped, horseshoe and city-gate cross-sections are typical examples of the channels of the second kind.

For the channels of the second kind, the governing equations for the critical and normal flow depths are implicit and no analytical solutions exist. For these channels the critical and normal depths are presently obtained by trial procedures, numerical and graphical methods, or explicit regression-based equations.

For circular channels, explicit equations are available for critical depth [2–5] and normal depth [5–15]. Tunnels carrying sediment at locations where the rock is stratified, soft, and very closely laminated are usually constructed in the form of the egg-shaped channel [16]. The geometry of egg-shaped cross section is very complex. The egg-shaped cross section consists of four arc segments. For egg-shaped channels, explicit solutions are available for critical depth [4,16] and normal depth [4,16,17]. A horseshoe cross section also consists of four arc segments. Due to the complexity of the horseshoe cross-section, a time-consuming trial-and error procedure is inevitable as a way to determine the critical and normal depths. Bijankhan and Darvishi [18] developed a direct relationship to determine the critical depth for USBR standard horseshoe channel. Liu et al. [19] derived iterative formulas for calculating critical depth of general horseshoe cross-sections. Liu et al. [20] also proposed iterative and estimation formulas to compute the normal depth of all horseshoe cross sections (standard Type I and Type II) over the three different portions of the channel. Vatankhah and Easa [5] developed explicit regression based equations to obtain both critical and normal depths in horseshoe channel over the entire practical range of flow depth (single equations).

According to the aforementioned studies, accurate explicit solutions for the critical and normal depths are available in the literature for the channels of the second kind such as circular, egg-shaped and horseshoe channels. However, for city-gate cross sections there are few studies on explicit equations for critical and normal depths over the entire practical range of flow depth with satisfactory accuracy. In practice, the standard I-type and II-type city-gate cross sections are widely used for free-surface water conveyance tunnels [21]. Using the curve fitting technique, Wang et al. [22] and Zhao et al. [23] developed explicit equations with low accuracy for critical depth of the standard I-type city-gate cross section with the maximum relative errors of estimation 5.1% and 6.4%, respectively. Liu et al. [24] developed an explicit critical-depth equation for upper portion

E-mail address: arvatan@ut.ac.ir

0955-5986/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.flowmeasinst.2012.07.003