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Choke-free flow in circular and ovoidal channels

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A comprehensive solution for circular and ovoidal channel sections is obtained under the condition of choke-free flow owing to a gradual and smooth rise in bed elevation. Generally, two practical cases of channel transition are considered: (*a*) rising bed elevation caused by a change in the position of the channel centreline; and (*b*) rising bed elevation caused by a decrease in the channel diameter. Considering the critical flow occurring downstream of the transition zone, the energy equation is solved with the aid of a numerical technique to determine the explicit equations for the maximum allowable bed rise under a given approaching regime. Moreover, to determine the limits of upstream flow depths (the choke-free regions) from the information on upstream channel geometry, rise in bed elevation and discharge, suitable graphical solutions are presented using dimensionless specific energy equations. These graphs can be utilised to choose the operating ranges of upstream flow depths for choke-free flow in both subcritical and supercritical upstream flow conditions. Since the downstream critical depth is required to determine the upstream operating range, the direct solutions for critical depths in circular and ovoidal channels are also presented. Finally, energy loss in the transition zone is considered by applying it in the proposed equations.

NOTATION

A	cross-sectional area
A_*	dimensionless cross-section area
c_i	transition head loss coefficient
D	conduit diameter
E	specific energy
E_*	dimensionless specific energy
$E_{1\text{new}}$	corrected specific energy
g	gravitational constant
H	conduit height
h_f	head loss
P	bed elevation difference between sections
Q	discharge
Q_*	dimensionless discharge ($= Q^2/(gD^5)$ for circular cross-section and $Q^2/(g\text{H}^5)$ for ovoidal cross-section)
Q'_*	dimensionless discharge ($= Q^2/(gD'^5)$ for circular cross-section and $Q^2/(g\text{H}'^5)$ for ovoidal cross-section)
Q''_*	dimensionless discharge [$= Q^2/(g(0{\cdot}5D\text{-}E_1)^5$] for circular cross-section and $Q^2/[g(5H/8\text{-}E_1)^5]$ for ovoidal cross-section)
T	width of the channel at the water surface
V	mean velocity of flow
y	depth of flow
α	energy coefficient
α_o	$\cos^{-1}(1-4\xi)$
α_T	$\cos^{-1}[(8/3)(\xi-5/8)]$
η	y/D relative depth in circular channel
θ	water surface angle in circular channel
ξ	y/H relative depth in ovoidal channel
φ	$\cos^{-1}[(8/7)(0{\cdot}625-\xi)]$

Subscripts

$2c$	critical flow condition at downstream section 1 and 2
	upstream and downstream flow conditions respectively
$*$	makes dimensionless

Superscripts

$'$ and $''$ downstream conditions in case 2 (decreased section)

1. INTRODUCTION

The upstream flow condition in a channel can be affected by bed rising. This phenomenon is said to be a 'choke' (Henderson, 1966). For designing a channel transition, it is pertinent to avoid a choke (i.e. choke-free flow is desirable). The choke-free concept is dependent solely on upstream and downstream flow conditions considering the unity Froude number as a limiting condition in the downstream transition zone.

Allen (1980) made the first step towards solving the choke problem. His investigations were then modified and applied by Liong. Liong (1984) put forward the solution of the problem owing to changes in bed elevation as well as width of rectangular channels and sketched the results in some design curves. Dey *et al.* (1990) reported the generalised solution of choke problem in triangular and parabolic channels for changes in bed elevation and cross-sectional shapes. Dey (1994) described the condition of choke-free flow in trapezoidal channels in which the channel sections were the same in the upstream and downstream of the transition zone. Dey and Sil (1998) also considered an extension of the work by Dey to a different trapezoidal channel condition where the bed is raised due to partial filling up of the channel bottom. Dey (1998) formulated the solution of choke-free flow through a