Gradually Varied Flow Computation in Channel Networks

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Abstract

A novel algorithm is presented to compute the water surface profiles in steady, gradually varied flows of open channel networks. This algorithm allows calculation of flow depths and discharges at all sections of a cyclic looped open channel network. The algorithm is based on the principles of (1) decomposing the channel network into units that are as small as possible; (2) solving the smaller units using an appropriate method; and (3) connecting the solutions for the smaller units to obtain the final solution for the whole network using the Shooting Method and (4) an iterative Newton–Raphson technique for obtaining the network solution. Obtained results show 56 percent reduction in Cpu time compared with previous method.

Keywords: Gradually varied flow, Water surface profile, Steady flow, Open channel network.

1. Introduction

In many situations, water-surface profile computations maybe required for steady flow in open-channel networks. Open-channel networks occur in a braided river system, such as in a mountainous area and in a delta. Open-channel networks also form an important component of an irrigation system.

Several efficient numerical techniques have become available for gradually varied flow (GVF) computations in the last four decades [1-2]. Classical numerical methods such as the standard step method, which are based on single step calculations, are well suited for single and series channels, but not for complex open channel networks. However, in many situations, GVF computations may be required for steady flow in open channel networks or a system of interconnected channels. Open channel networks occur in braided river systems, divided shipping channels, interconnected storm water systems, or irrigation canal systems [3]. The Brahmaputra–Ganga deltaic system in the Indian subcontinent [4] and the Mekong river basin in South East Asia [5] are a few examples of interconnected rivers with complex flow situations.

Although considerable research has been carried out in recent years with regard to unsteady flows in channel networks [6-9], not much attention has been paid to the problem of steady GVF computation in open channel networks. Wylie [3] developed an algorithm to compute the flow around a group of islands, in which the total length of the channel between two nodes is treated as a single reach to calculate the loss of energy and the node energy is used as a variable. In this method, the channel is not divided into several reaches as in a finite difference method. A reach is defined as the portion of the channel between two finite-difference nodes. Chaudhry and Schulte [10] presented a finite difference method for analyzing steady flow in a parallel channel system. Their formulation is in terms of the more commonly used variables, flow depth and discharge. Schulte and Chaudhry [11] later extended their method for application to general looped channel networks. In their method (referred to as the Direct Method in the rest of the text), a channel i in the system is divided into several reaches, N_i. The continuity and the energy equations can be written in terms of flow depths, and flow rates for all the reaches, resulting in a total of $2\sum_{i=1}^{M} N_i$ equations because there are N_i+1 nodes in any channel i and there are M channels in the system. Additional 2M equations, required for closing the system, are obtained from the boundary conditions and the compatibility conditions at the junctions. The system of nonlinear simultaneous equations resulting from the above formulation is solved using the Newton–Raphson iteration technique. This requires inversion of the system Jacobian for every iteration step. In this formulation, the size of the Jacobian increases if the number of reaches in each channel is increased to increase accuracy. Therefore the above method becomes computationally intensive for large unstructured channel networks.

Sen and Garg [12] developed an efficient solution technique for one-dimensional steady and unsteady flow in a general channel network system. In their method, the number of equations to be solved simultaneously during any iteration is only four times the number of branches of the network. This resulted in a significant improvement in the computational efficiency as compared to the existing methods. Naidu et al. [13] followed a different solution