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Numerical analysis of slid gate and neyrpic module intakes outflows in unsteady flow conditions

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Abstract Since the intakes outflow variations have an impact on network performance, it is necessary to evaluate the behavior of different types of intake structures in unsteady flow condition. In the present study, a computer model has been developed in which unsteady Saint–Venant flow equations have been discretized using finite difference and Crank–Nicolson method. Water surface elevation at junctions is calculated implicitly using matrix properties and influence line technique. After model verification, main channel of Miandarband irrigation network and its five branches were simulated. The result showed that without any operation instruction, a 10% decrease in the upstream flow discharge will reduce the slid gate, Neyrpic single orifice Module and double orifice Module intakes outflows for about 17.6%, 3.04% and 2.56%, respectively. With operation instruction, the maximum loss of flow volume is 707 m^3 during the first 10 h of operation for intake with slid gate.

1. Introduction

Opening and closing gates and water level regulating structures in irrigation networks establish unsteady flow in channels that adversely impacts the efficiency of these structures. The temporal and local variations in discharge along with the flow depth change produce a complex hydraulic condition in irrigation networks. Without using numerical models, accurate evaluation of flow pattern and behavior is very difficult. The water delivery irrigation channels must provide a sustainable and appropriate amount of flow to specific locations at suitable times. For any channel, this process is affected by the methods used to operate and control the channel and by rate of change in discharge. In order to shorten response time, limit water level fluctuation, and maintain the stability and performance of automatic control channel systems, appropriate automatic channel control methods should be adopted (Reddy, Blesa et al. and Fleiu et al.) [1–3]. The monitoring and control of water delivery is becoming an important subject recently. Studies have shown that channel automation may enhance the flexibility of a water delivery system, which will allow communities and agricultural planers to conserve water (Lozano et al.) [4].

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The main purpose of an automatic channel control is to optimize the water supply in order to match the expected demands at the offtake level. In practice and with the traditional management tools, it is very difficult to manage open-channel water conveyance and delivery systems, especially if there is a demand-oriented operation (Clemmens) [5]. Shang Yizi et al. [6] showed that the developed control system rather than the system in current used had considerable potential to closely match discharge at the downstream check structures with those orders by water users while maintaining the water level throughout the length of the channel. Channel automation has been developed for many years, to the point where most new channel designs and channel modernization plans have some level of automation (Rodriguez et al. and Ghumman et al.) [7,8]. Channel control algorithms have a fathomless effect on the overall efficiency of the channel projects. The water management can be improved by refining the channel control algorithms. Many channel control algorithms have been developed based on simulation (Lozano et al. and Clemmens and Strand) [4,9]. However, few algorithms have been implemented in the field (Aguilar et al.) [10]. Fengxiaobo and Wang Kang [11] presented a relationship between the automatic control method and stability of the open channel using a numerical simulation in unsteady flow conditions.

Channel automation has become a significant study area. However, many of studies only use numerical simulators, without having the possibility to test and verify their mathematical approaches with physical models. In this research efforts have been made to bridge the theory with the real word. Due to importance of unsteady flow conditions and its effects on irrigation networks, a computer model was prepared in which partial differential equations for non-uniform unsteady flow (Saint–Venant equation) are solved by finite difference method and alternative technique. Matrix properties and influence line technique have been employed to determine water surface elevation at any time step. The model is able to calculate and evaluate the effect of system inflow changes on intake or check structures discharges. The present model is capable of simulating flow in irrigation networks in the presence of hydraulic structures. This model would eliminate the requirements for the expensive filed studies. This model is also able to evaluate the operational routines and proposed modifications to optimize irrigation network management.

2. Material and methods

Ordinarily, Saint–Venant equations are used to define one-dimensional unsteady non-uniform flow in open channels. The Saint–Venant equations, momentum and continuity equations can be expressed as follows:

$$\frac{\partial Q}{\partial t} - \frac{2\beta Q T_W}{A}\frac{\partial Z}{\partial t} + \frac{2\beta Q q_L}{A} - \beta\frac{Q^2}{A^2}\frac{\partial A}{\partial x} = -gA\frac{\partial A}{\partial x} - g\frac{n_m^2 Q|Q|}{AR^{(4/3)}} \quad (1)$$

$$\frac{\partial Q}{\partial x} + T_W\frac{\partial Z}{\partial t} = q_L \quad (2)$$

where Q = discharge, A = flow area, Z = water surface elevation, T_w = water surface width, β = momentum coefficient, n_m = Manning's roughness, R = hydraulic radius, qL = lateral discharge per unit length of channel (input +, output −). Eqs. (1) and (2) are discretized using finite difference method. The length of network channels separately is divided to several nodes and is discretized in the form of staggered grid. Linear form of continuity equation on any node in the channel network is as follows (Eq. (3)):

$$a_{pi} \times Q_{i-1}^{n+1} + b_{pi} \times Z_i^{n+1} + c_{pi} \times Q_{i+1}^{n+1} = d_{pi} \quad (3)$$

where

$$a_{pi} = -\frac{\theta}{x_{i+1} - x_{i-1}} = -c_{pi} \; b_{pi} = \frac{T_{w_i}^n}{\Delta t}$$

$$d_{pi} = -\frac{(1-\theta)(Q_{i+1}^n - Q_{i-1)}^n}{x_{i+1} - x_{i-1}} + \frac{T_{W_I}^n \times Z_i^n}{\Delta t} + \frac{Q_{L_i}^{n+1}}{x_{i+1} - x_{i-1}}$$

Also momentum equation can be discretized for each grid as follows (Eq. (4)):

$$a_{mi} \times Z_{i-1}^{n+1} + b_{mi} \times Q_i^{n+1} + c_{mi} \times Z_{i+1}^{n+1} = d_{m_i} \quad (4)$$

where

$$a_{m_i} = -\frac{\beta Q_i^n T_{W_i}^n}{A_i^n \times \Delta t} - \frac{gA_i^n\theta}{x_{i+1} - x_{i-1}}$$

$$b_{mi} = \frac{1}{\Delta t} + \frac{2\beta\theta Q_{L_i}^{n+1}}{(x_{i+1} - x_{i-1})A_i^n} - \frac{\beta Q_i^n}{(A_i^n)^2} \times \frac{A_{i+1}^n - A_{i-1}^n}{x_{i+1} - x_{i-1}} + \frac{gQ_i^n n_{m_i}^2}{A_i^n R_i^{4/3}}$$

$$c_{mi} = -\frac{\beta Q^{n_i} T_W^{n_i}}{A_i^n \times \Delta t} + \frac{gA_i^n\theta}{x_{i+1} - x_{i-1}}$$

$$d_{mi} = \frac{Q_i}{\Delta t} + \frac{2\beta(1-\theta)Q_{L_i}^{n+1}}{(x_{i+1} - x_{i-1})A_i^n} - \frac{\beta Q_i^n T_W^{n_i}(Z_{i+1}^n + Z_{i-1}^n)}{A_i^n \Delta t} - gA_i^n(1-\theta)\frac{Z_{i+1}^n - Z_{i-1}^n}{x_{i+1} - x_{i-1}}$$

In Eqs. (3) and (4), n and $n+1$ indicate time step and θ is time related weight parameter. The discretization scheme is completely explicit as θ is set to zero or implicit as θ is set to one. Eq. (5) shows matrix form of all linearized momentum and continuity equation for a channel with discharge hydrograph and stage-discharge boundary condition for upstream and downstream, respectively.As shown in Eq. (5), right-side matrix is divided into three matrixes.

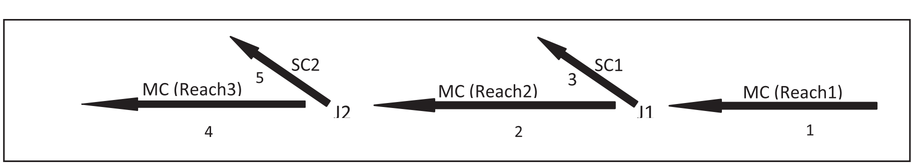

Figure 1 Channel branch of second order from main channel.