WinGate Software for Discharge Calibration of Gated Check Structures

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ABSTRACT

WinGate is a new interactive computer program that provides discharge calibration of canal check structures containing radial gates and/or vertical slide gates. The software provides a graphical user interface to define dimensions and hydraulic properties of the canal, check structure, and gates, and enables the user to compute discharge for specific gate settings or the gate openings needed to pass a specified discharge. The software utilizes the latest energy-momentum calibration equations that enable calibration for a wide range of upstream and downstream cross sections. Rating tables covering ranges of canal water level conditions can be generated for both free flow and submerged flow cases.

INTRODUCTION

Many irrigation delivery systems are being modernized today to provide remote, real-time monitoring and control capabilities. Flow measurement is a key element of most modernization efforts and is often provided by dedicated flow measurement structures, such as weirs and flumes, or modern instruments, such as acoustic Doppler flow meters. At points of flow control, such as in-line checks and bifurcations, it is often desirable to combine flow measurement and control functions by calibrating existing gates for flow measurement. This can provide a monetary savings as well as eliminate lag between changes in gate setting and changes in measured flow rate. The software described in this paper implements the energy-momentum calibration method for both radial gates and vertical slide gates.

Modeling of flow through sluice gates is a classical problem of theoretical and experimental hydraulics. Until recently, most efforts to calibrate sluice gates for flow measurement relied on just the energy equation. Henderson (1966) outlined a method for using the energy equation upstream from the vena contracta and the momentum equation downstream from the vena contracta. Working specifically with radial gates, Clemmens et al. (2003) developed empirical relations for upstream energy loss and velocity distribution, downstream wall pressure weighting factors, and an energy correction factor that together comprised a practical Energy-Momentum (E-M) method. The method offers the potential for improved accuracy in a wide variety of structure configurations and in the transition zone from free to submerged flow. The

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new method requires iterative solution of the energy and momentum equations and associated empirical relationships.

The E-M method has seen further development since its introduction. Wahl (2005) developed an improved energy correction term utilizing the large data set of Buyalski (1983). Lozano et al. (2009) tested it for vertical slides gates and found the method to be sound. Castro-Orgaz et al. (2010) proposed the use of energy and momentum coefficients to account for nonuniform velocity in and above the vena contracta jet. In a companion paper, Clemmens and Wahl (2012) propose relations for energy and momentum coefficients that apply only to the vena contracta jet (significantly different from those of Castro-Orgaz et al.) in order to eliminate the energy correction term first introduced by Clemmens et al. (2003).

To implement the E-M calibration technique, the interactive WinGate computer program has been developed that allows one to compute the flow through a complete check structure made up of multiple gates. Solution for the flow rate at specified gate settings is possible, as well as solution for the gate settings needed to yield a target flow rate. This paper describes the software in its current state of development.

FLOW SITUATION

Flow through a radial gate is shown in Figure 1. The flow rate through a gate is a function of three primary variables: upstream head, downstream head, and gate opening. In addition, the gate seal type has an influence, and two states of flow are possible, either free or submerged. The energy-momentum method applies the energy equation from position 1 to position 2 (the *vena contracta*), and the momentum equation from position 2 to position 3. Position 3 should be sufficiently far downstream that the flow is relatively uniform and free of excessive turbulence. Use of the momentum equation in the downstream reach avoids problems with estimating energy loss in the variety of channel configurations that may exist downstream from the gate, but requires estimation of forces on the downstream channel boundaries.

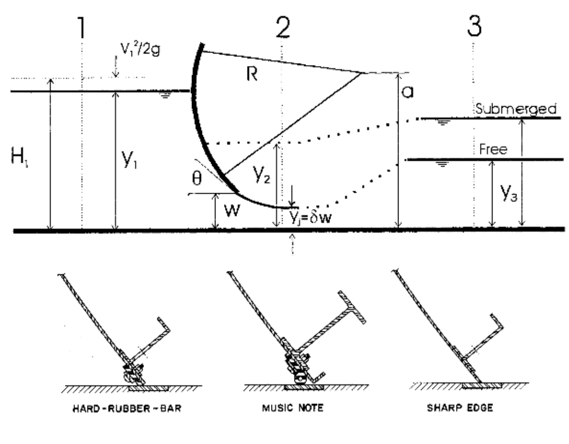

Figure 1. — Variables affecting radial gate calibration.

COMPUTER PROGRAM

WinGate is a stand-alone application written in Microsoft Visual Basic.NET. The user interface provides a graphical environment for entering check structure and gate dimensions and other properties (Figures 2-4). Once a structure has been defined in the software, it can be saved in a commented text file format for later reuse. Since the data file is self-documenting, with an example of the data file in hand, text files defining other structures can also be created externally to the software when it would be efficient to do so. Check structure data can also be exported to a batch file format that can be replicated to create batch input files that can be processed by the program to analyze multiple structures or widely-varying scenarios. This feature was included to facilitate analysis of experimental data sets during development of the Energy-Momentum algorithm.

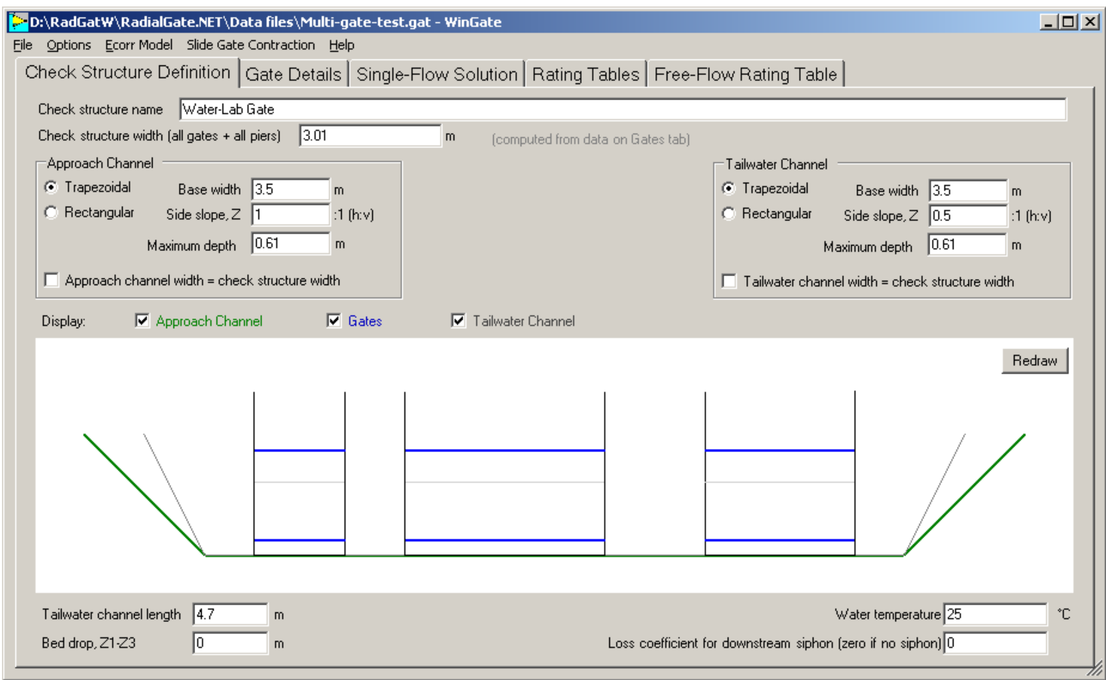

Figure 2. — Entry of check structure dimensions and properties.

Internally, the software uses an object-oriented architecture. Check structure objects are defined by an upstream section, downstream section, and a collection of gates, among other properties. Each of the components of a check structure is itself an object, and the definition of each object is given in a class module. Thus, there are class modules for gates, the gate collection, channel sections, and complete check structures, which can also include some gate bays that are occupied by weirs. The bulk of the iterative program code resides at the lowest level, within subroutines of the gate class. When the flow rate through an individual gate is needed at a higher level in the program (e.g., to be added to the flows through other gates to sum the flow through a check structure) the higher level object simply asks the gate class to return the flow rate property of the lower level object. This initiates an iterative solution of the energy and momentum equations for that gate. Another level of iteration for the structure as a whole is often needed to fine-tune estimates of energy and velocity head for the upstream and downstream channels, which cannot be fully determined until the total flow is known. With this architecture, the resulting high level subroutines are relatively simple in form.

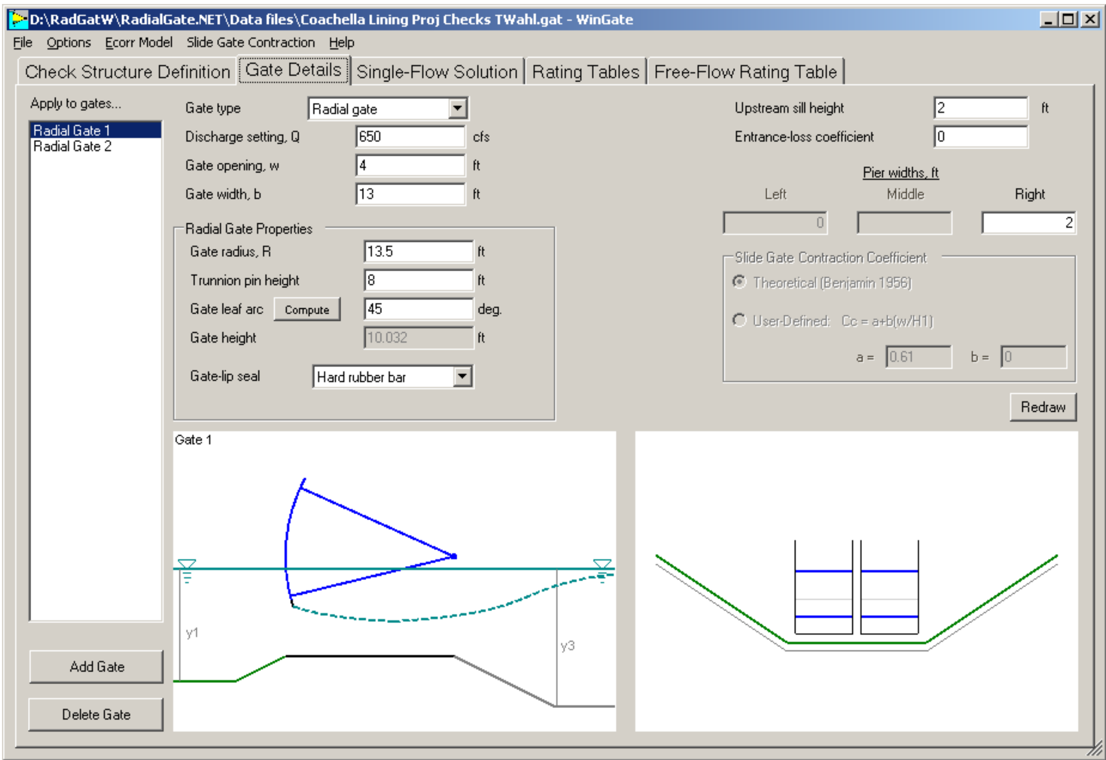

Figure 3. — Entry of gate dimensions and other properties for a radial gate.

Since flows through gates are determined individually, this architecture requires subdivision of the downstream canal into sections that can be associated with each specific gate. This is needed for the momentum equation to be applied to each gate, since momentum flux is a quantity integrated over a specific area. The subdivision method used in the program is rather arbitrary; the channel is divided at the centerline of each pier separating adjacent gates. No testing has yet been done to evaluate the sensitivity of the results to the subdivision method. In reality, momentum can cross this arbitrary boundary, affecting the submergence of individual gates. It is expected that the exact flow through each gate may not be perfectly modeled, but the total flow through the check structure should be reasonable. A similar subdivision is not needed for the upstream channel, since the energy head of the upstream channel can be determined as a whole and is equally applicable to all of the gates. The assumption is that the upstream water level is being measured at a point upstream from any gate piers, where the energy head across the width of the channel is uniform.

At present, the software offers several methods for determining the contraction coefficient, depending on gate type. For radial gates, the user specifies the seal type of the gate and the contraction coefficient is determined from relations developed by Wahl (2005) from data obtained by Buyalski (1983) on laboratory models. For vertical slide gates (Figure 4), the program offers the choice of determining the contraction coefficient from the theoretical relation of Benjamin (1956) or an empirical approach in which the coefficient is related to the relative gate opening. Further research, especially on field-scale installations, would be valuable to refine this aspect of the software.

The greatest focus of research on the E-M method has been the energy correction factor first developed by Clemmens et al. (2003). The software at present supports the use of this factor or the version developed by Wahl (2005). Eventually we expect to support only the new approach developed by Clemmens and Wahl (2012), which utilizes energy and momentum coefficients in place of the energy correction factors.

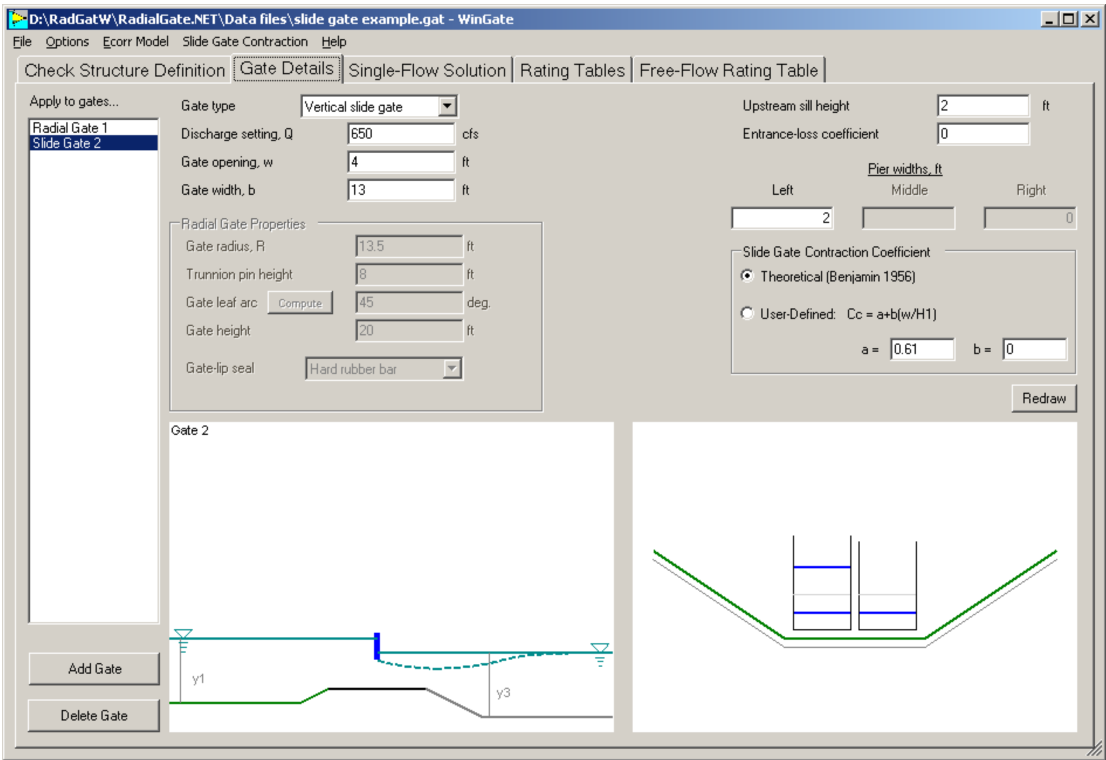

Figure 4. — Entry of gate dimensions and other properties for a slide gate.

PROGRAM OPERATION

The program operates in two basic modes, a single-flow solution (Figure 5) which provides detailed information about each gate, and a rating table mode (Figures 6-7) that gives results for a range of upstream and downstream water levels. In each mode, the program can solve for the flow through the check structure at given gate settings or the gate setting needed to produce a given flow rate.

The single-flow solution can be especially useful to a water manager who operates multiple gates, but wishes to use just one gate for making flow adjustments. A base data file defining the check structure could be quickly loaded and actual gate positions could be adjusted using the graphical user interface. The flow rate through each gate and the check structure as a whole could then be computed, or target flow rates through each gate could be entered and the software could determine the appropriate opening for each gate. The solution process is very fast, making it feasible to use the program to support real-time operational decisions.

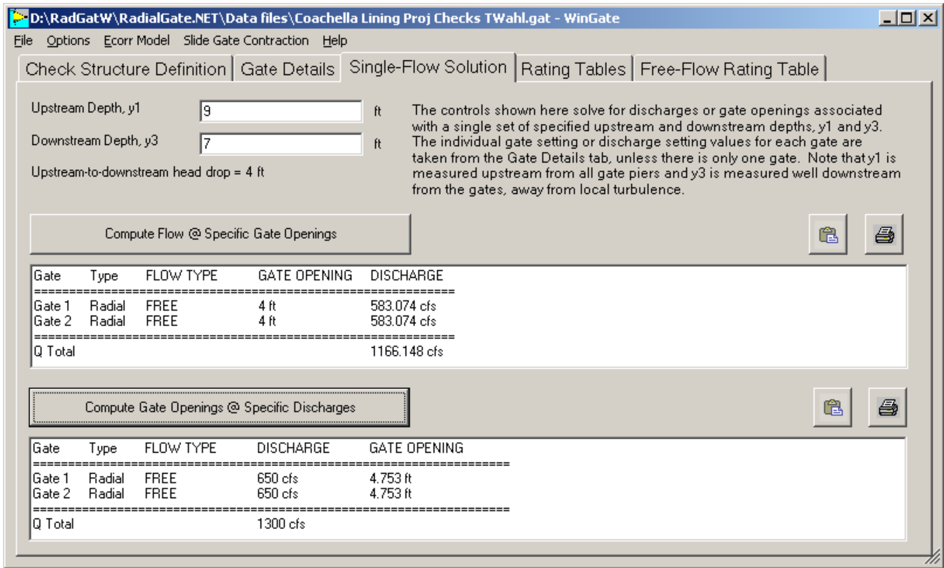

Figure 5. — Solutions for single flow conditions, yielding either discharge (top) or gate settings (bottom).

Rating tables are available for both submerged flow situations and gates that operate solely in free flow. The rating table mode can only be applied to check structures in which all gates are similar; the flow is computed assuming that all gates are set to the same position, or a single gate setting is computed that could be applied uniformly to all gates to produce a desired total flow. For a gate that experiences submerged flow, multiple tables are required to provide information covering the range of upstream and downstream water levels, as well as a varying gate setting or discharge. For a gate that always operates in free flow, the program offers a free-flow rating table that condenses the entire range of operations (varying upstream water level and varying gate setting or discharge) into a single table.

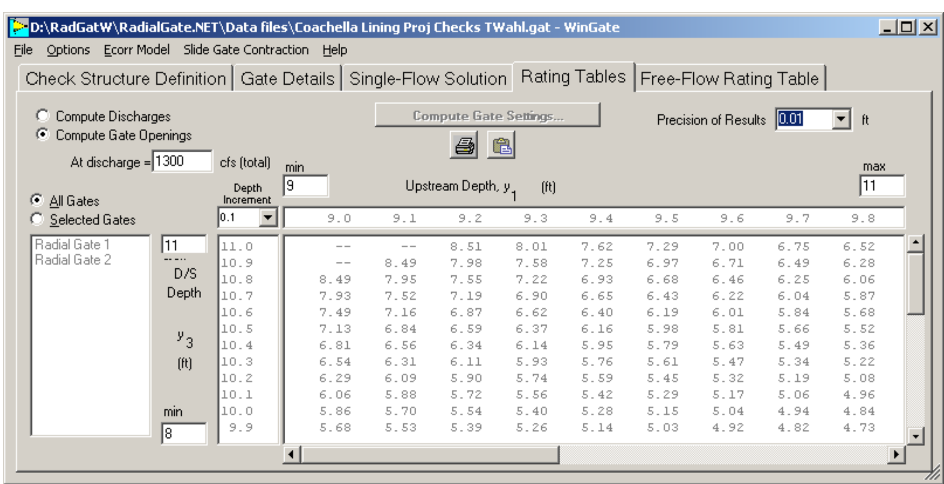

Figure 6. — A rating table showing total check structure discharge for a range of upstream and downstream water level conditions.

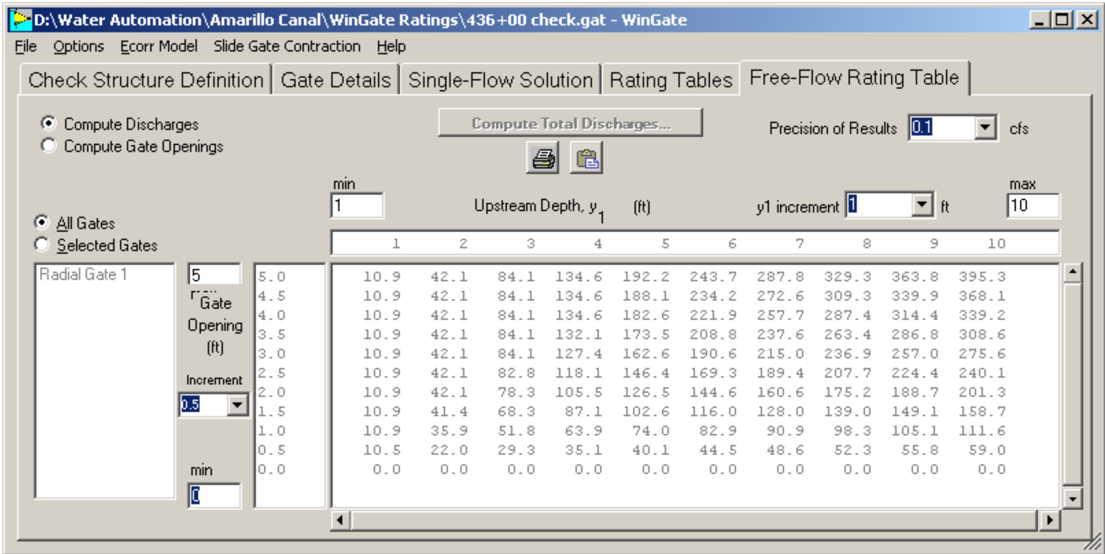

Figure 7. — A rating table for free flow conditions.

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