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Software for Discharge Calibration of Canal Radial Gates

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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 instrumentation, 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. The gate calibration methods and software described in this paper are being developed with the goal of achieving measurement accuracy comparable to that of dedicated flow measurement structures and instruments.

Radial gates are a commonly used control gate on large irrigation and drainage projects. They provide economical control of large flows with a mechanically efficient gate and operator design. Modeling of flow through radial gates (and all sluice-type gates) has been a classical problem of theoretical and experimental hydraulics. Until recently, most efforts to calibrate gates for flow measurement relied on the energy equation. A new calibration technique, the Energy-Momentum method (Clemmens et al. 2003), uses both the energy and momentum equations, and offers the potential for improved accuracy in a wider variety of structure configurations, and in the transition zone from free to submerged flow. The new method requires iterative solution of the energy and momentum equations and associated empirical relationships that have been developed through laboratory testing.

To facilitate the use of the new calibration technique, an interactive computer program, WinGate, has been developed that allows one to compute the flow through a complete check structure comprising 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 architecture of the software in its current state of development. The Energy-Momentum method will be described only conceptually; for more detail the reader is directed to Clemmens et al. (2003) and

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Wahl (2005). Future publications will document improvements to the method that are being developed now using data collected from recent physical model tests.

ENERGY-MOMENTUM METHOD

Flow through a radial gate is depicted 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 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. The energy equation applied to the upstream reach contains empirical factors that account for energy loss on the upstream side of the gate and the effects of flow distribution at the vena contracta. An empirical energy correction is also applied to account for the effects of partial submergence of the vena contracta during the transition from free to submerged flow (Clemmens et al. 2003). The momentum equation applied to the downstream reach includes drag coefficients and empirical weighting factors for estimating hydrostatic forces in the expanding downstream channel. Wahl (2005) investigated alternative methods for estimating the energy correction term, and recent laboratory work may yield further improvements to this part of the method. Clemmens (2004) identified issues related to the application of the method to structures with multiple gates that are not operated in unison.

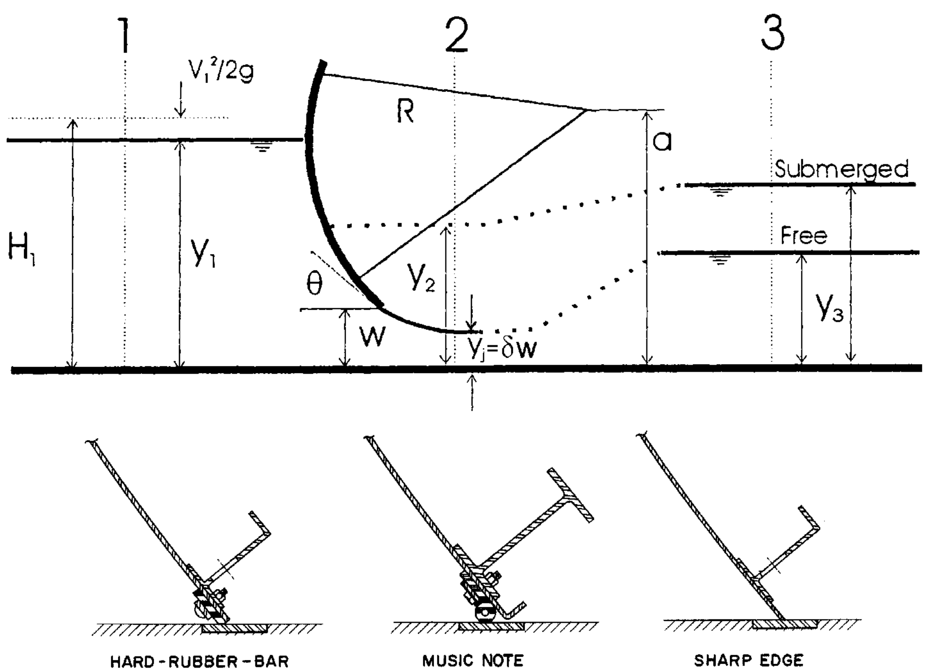

Figure 1. — Variables affecting radial gate calibration.

WINGATE COMPUTER PROGRAM

The WinGate computer program developed for applying the Energy-Momentum method is written in Microsoft Visual Basic.NET and runs as a stand-alone application. The user interface provides a graphical environment for entering check structure and gate dimensions and other properties. 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 laboratory data during development of the Energy-Momentum algorithm.

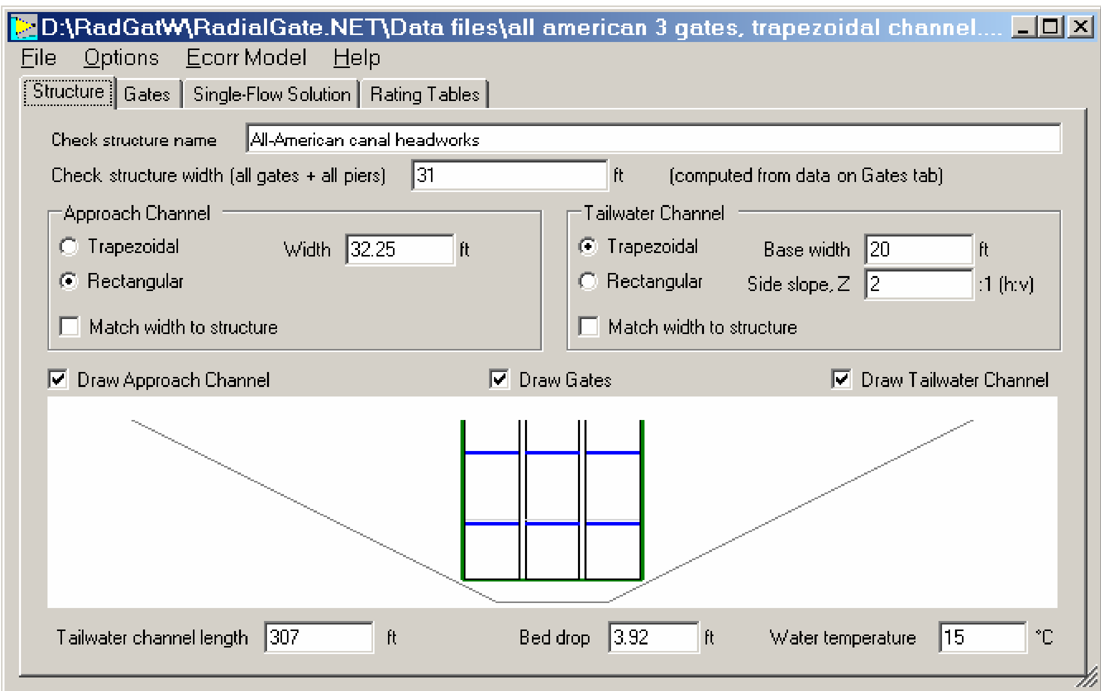

Figure 2. — Entry of check structure dimensions and properties.

Internally, the software uses an object-oriented architecture. Check structure objects have 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. The bulk of the iterative program code resides at the lowest level, within Property Get 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.

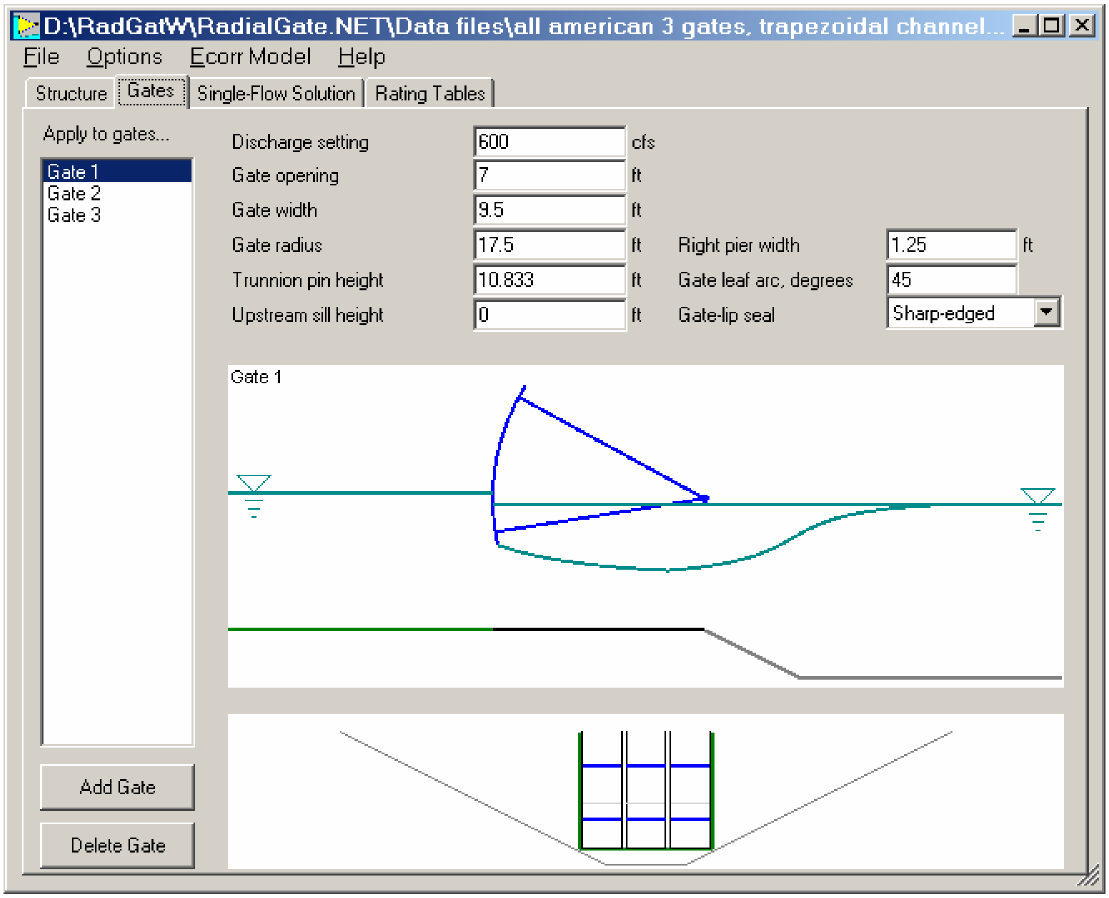

Figure 3. — Entry of gate dimensions and other properties.

Since flows through gates are determined individually, one necessity of this architecture when there are multiple gates is a subdivision of the downstream canal into sections that can be associated with each specific gate. This is needed to allow 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. 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.

APPLICATION

The program operates in two basic modes, a single-flow solution (Figure 4) which provides detailed information about each gate, and a rating table mode (Figure 5) 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 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.

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 incorporate the use of the program into real-time operational decisions.

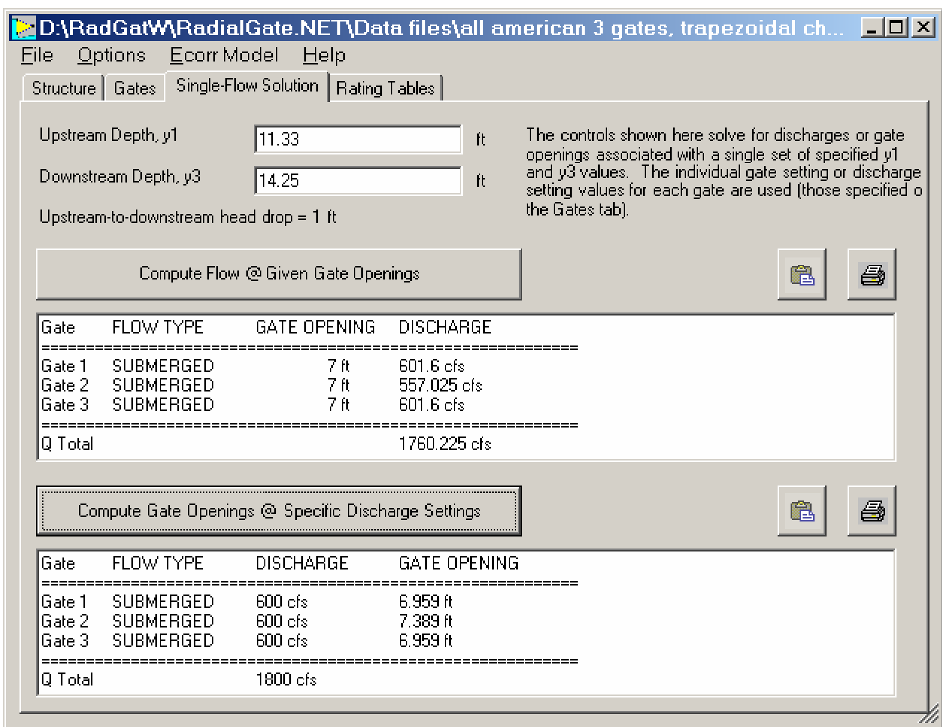

Figure 4. — Solutions for single flow conditions, yielding either discharge (top) or gate settings (bottom).

DEVELOPMENT STATUS

At this time of this writing the software is still under development, although the majority of the key features are in place. Working trial versions of the program have

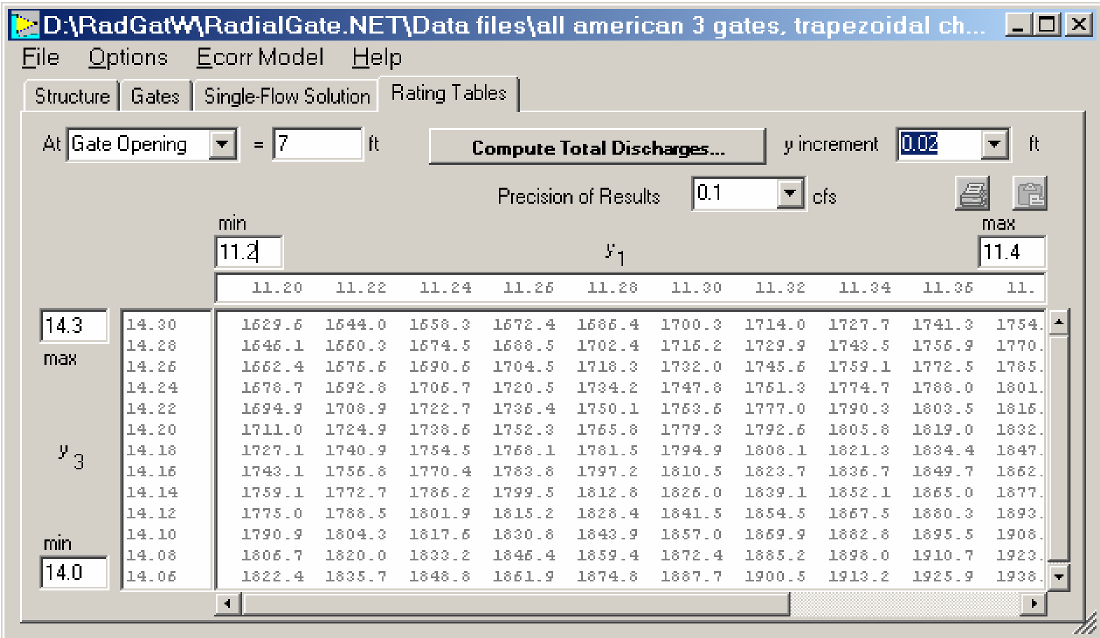

Figure 5. — A rating table showing total check structure discharge for a range of upstream and downstream water level conditions.

been made available to interested parties. Graphical output of gate rating curves has not yet been provided, and work is still ongoing to improve the implementation of the energy correction term used in the algorithm. We also hope to develop a means of simplifying rating tables into closed-form equations that could be integrated into remote terminal units (RTUs) used in canal control systems.

Other future developments are also being considered. One possibility is porting the algorithm to a set of Visual Basic for Applications routines that could be called as macros from Microsoft Excel. We also have interest in programming the algorithm into an RTU using IEC 61131-3 compliant programming tools. Finally, the application of the algorithm to vertical slide gates is possible, with some modifications to account for differences in contraction coefficients, seal configuration, and the effects of side contraction.

REFERENCES

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