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CanalCAD

Dynamic Flow Simulation in Irrigation Canals with Automatic Gate Control

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The CanalCAD system of programs simulates unsteady flow in irrigation canal systems with automatic gates. CanalCAD comprises the synthesis of mature, reliable dynamic-equation solution techniques; a menu-driven interface for canal definition and results processing; and user-customized access to gate-control algorithms. CanalCAD is designed for use on IBM-compatible PC's in the design, analysis, and operation of irrigation canals comprising subcritical flow in a single in-line system of pools and appurtenant structures including turnouts, in-line weirs, check structures, culverts, storage reservoirs, etc. The system is designed to provide a high degree of user guidance in canal description and simulation diagnosis.

Background

In the spring of 1991, the Imperial Irrigation District (IID) and Dr. Charles Burt of Cal Poly's Irrigation Training and Research Center (ITRC) entered into discussions about possible development of an irrigation-canal simulation program responding to the needs of IID. These discussions, building on earlier discussions and analyses of the ASCE Task Committee on Irrigation Canal System Hydraulic Modeling led by Dr. A.J. Clemmens of the ARS Water Conservation Lab, led to contractual arrangements between the authors and IID to implement existing canal simulation techniques in a new user interface.

The resulting CanalCAD system of programs described herein represents an extremely productive avenue of future development in computational hydraulics. This avenue involves embedding mature, robust, proven computational techniques in a state-of-the-art user interface

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for communication with the user, with expert user support for effective and efficient use of the simulation technology. In CanalCAD, the simulation technology is based on algorithms developed by Jean Cunge, Alexandre Preissmann, Guy Chevereau, Forrest Holly and others at SOGREAH Consulting Engineers, and published by Cunge et al (1980). Implementation of these techniques in CanalCAD was performed in collaboration with Laboratoire d'Hydraulique de France (LHF).

CanalCAD comprises, in addition to the simulator, several new program products, including the primary user-interface program CanalCAD, the simulator data pre-processor EZCAR, the initial-gate-position analyzer EZGAT, and the simulation diagnostic program MUSTARD. In addition, the regulation interface of the simulator was considerably modified for the CanalCAD implementation.

The CanalCAD system provides PC-based support for the design and analysis of irrigation canal systems with both generic and user-customized gate-control algorithms. In its original version, CanalCAD is limited to subcritical flow in a single suite of canal pools in series, with off-line storage reservoirs and local gate controllers.

CanalCAD is owned by three parties: Imperial Irrigation District, the Iowa Institute of Hydraulic Research, and the Laboratoire d'Hydraulique de France. All CanalCAD sales and support are handled through Dr. Forrest Holly of the Iowa Institute of Hydraulic Research. Dr. Holly may be reached at (319) 335-5239. Additionally, short courses covering CanalCAD and strategies for canal control are provided by Dr. Charles Burt of the Irrigation Training and Research Center of Cal Poly. Dr. Burt may be reached at (805) 756-2434.

Program Structure

CanalCAD consists of a system of programs, as outlined briefly above. However, the user need only access the CanalCAD shell and may view it as a single program; access to CanalCAD's analytical tools, such as the simulator, is transparent. CanalCAD utilizes an hierarchical menu system whereby the basic logical sequence required for canal design or analysis is built into the menu's structure. The user is protected (in so far as possible) from hydraulically illogical data input sequences and combinations.

CanalCAD provides the following services via its main menu: (1) File and printer management, (2) data input via an editor specific to irrigation-canal hydraulics, (3) execution of the simulator, and viewing of accompanying post-mortem diagnostics, (4) viewing of both tabular and graphical output of water levels, gate positions, etc. These services are described as follows:

File Management

The File and printer management section is self-explanatory, and amply serves the needs

of the CanalCAD user. It is especially useful to users not familiar with the DOS operating system; they can accomplish almost all file management tasks using CanalCAD's menu commands.

CanalCAD Input

The CanalCAD Input sections provide the following services: (1) input of canal layout data; (2) input of control data for check structures with user supplied control algorithms and data; (3) input of schedule information, i.e. all time dependent data; and (4) editing and compilation of user defined algorithms.

The "Layout" section allows input of the basic canal topology, geometry, and related physical attributes. The user may randomly insert, delete, and modify the canal in terms of its pools (up to 50), and its reaches and devices (up to 50 per pool). In CanalCAD, pools comprise one or more reaches, within each of which the cross-section, roughness, and other related data are constant throughout the reach length. Within reaches the user may install devices, such as turnouts, weirs, culverts, reservoir outlets and inlets (with their appurtenant reservoir structures), and in-line checks (which define the end of each pool). The Layout section editor includes automatic re-calculation of downstream stations and elevations. That is, when the user modifies the station or elevation of a device, or the length or slope of a reach, the effects will ripple through all downstream devices and reaches automatically; and, in the case of a slope change in a reach, all devices within that reach will receive their new elevation.

Note that most data input fields (in this section and later sections) feature dynamic range checks which depend on relevant user responses elsewhere. These range checks provide a first line of defense against simulation errors that might otherwise occur. Also, the CanalCAD shell supports use of either the SI (Metric) or ES (English) systems of units; furthermore, in most instances the user may toggle back and forth between the two while entering or viewing data.

The "Control Parameters" section is accessible only if the user specifies a check structure with an associated user-defined control algorithm. This control algorithm must be written as a FORTRAN subroutine and must use a SUBROUTINE statement with a predefined argument list. The FORTRAN subroutine is compiled and linked with the remaining simulator object code modules to create the simulator executable. In this section the user specifies the setpoint location controlled by the gate and may additionally specify user-supplied data specific to the gate's FORTRAN control algorithm. The user may then access this data within the customized FORTRAN subroutine via the argument list, thus obviating the need for re-compilation when only data changes are necessary. Many control algorithms require adjustment of coefficients to obtain optimum performance; CanalCAD allows the user the convenience of doing this from within the CanalCAD shell.

The "Schedules" section allows input of time-dependent information, as needed by the canal layout defined earlier. For example, the headworks will have a schedule associated with it such as discharge or level; manual gates, turnouts, etc., will have their schedules as well.

profiles available through this code, possibly including on-screen evolution in time, globally or by pool.

Branched and Looped Canal Systems

The simulator system routinely accommodates any level of canal topology, from the single channels of CanalCAD to arbitrarily branched or looped systems, and this topological generality is entirely data driven. The CanalCAD system could be endowed with a new "layer" of topological information, by which a canal system in the present version becomes just one of many interconnected canal systems. In addition, inter-connectivity of reservoirs could be accommodated if judged useful.

User-Customized Supervisory Control

In its original version, CanalCAD is limited to local control, in the sense that the canal information available for control of a check structure is limited to water-surface elevations at five points each in the immediate upstream and downstream pools. A generalization of CanalCAD to include supervisory control would make any and all information in the canal system available for control decisions at a particular check structure; it would also provide a mechanism for simultaneous supervisory control of any or all check structures, based on canal information from anywhere in the system.

Non-Prismatic Canal Sections

Description and use of arbitrary, non-prismatic canal sections is a standard feature of the simulator. The local prismaticity of the original CanalCAD system could easily be generalized to accommodate any combination of unique cross sections and locally prismatic canal reaches.

Manual "Zanjero" Check Structures

In the original version of CanalCAD, in-line canal checks must either be manually pre-scheduled with regard to gate position, or controlled automatically. A third possibility, one that emulates some canal operating schemes more closely, is to have checks that are periodically reset to deliver scheduled discharge much in the same way that the present Zanjero turnout is periodically reset, its delivery drifting away from the target as the water-level in the canal varies.

Mixed-Regime (transcritical) Flow

CanalCAD, through the essential subcritical nature of the simulator, is limited to simulation of the subcritical flow. Current research at the Iowa Institute if Hydraulic Research is focussed on developing a generalized solution algorithm for mixed-regime flow, including moving hydraulic jumps. When this research has come to fruition, it may be possible to implement it in the simulator and thus to endow CanalCAD with mixed-regime capability.

CanalCAD shell builds on this legacy by adding predefined devices appropriate to irrigation canals, access to user-defined gate control algorithms, state-of-the-art data input, automatic initial conditions, intelligent post-mortem diagnostics, etc.

CanalCAD Results

The final section provides the user the opportunity to view the results of the simulation. The user may view, as a function of time, pool water levels at quarter-points (i.e. at the beginning and end of each pool, the midway point, and the quarter-points), and device data such as automated gate positions, turnout flows and volumes, check flows, pool volumes, etc. Output items may be individually selected or conveniently selected or de-selected by pool. The output may be viewed in both tabular and graphical format.

Longitudinal profiles are also available for pre-selected simulation times, but are approximate and may be viewed for the canal as a whole only; the longitudinal profiles, as currently implemented, provide the user opportunity to verify the general coherency of the input and output.

Future Development

In its original incarnation (as described here), CanalCAD responds to a set of specifications agreed upon at the outset of its development. It is expected that the features incorporated in CanalCAD based on these specifications will satisfy the needs of most users most of the time.

As experience in use of CanalCAD accumulates, the need for it to incorporate additional features will surely become apparent. Since the simulator, in its primitive form, already incorporates much more generality of topology, topography, and results resolution than is exploited in the CanalCAD system, it is anticipated that further development will be concentrated on the user interface, rather than on the simulator itself. Indeed, the interface has been designed for as much flexibility as possible in future development of CanalCAD.

The CanalCAD developers anticipate preparing a minor update of the system based on initial user feedback. Several possible areas of more substantive CanalCAD development and generalization might include, but not be limited to, the following:

Precision Water-surface profiles

There is a third member of the simulator family that is capable of processing longitudinal profiles of water-surface elevation, depth, discharge, velocity, energy slope, etc. with all the resolution available in the calculation (i.e. every computational point) at any time during the simulation. This includes profiles of maximum and minimum envelopes of all variables). One can anticipate generalizing the CanalCAD program to acquire and display the full range of

profiles available through this code, possibly including on-screen evolution in time, globally or by pool.

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Generalized Culverts

The present version of CanalCAD accommodates only a single in-line culvert, with approximate treatment of transitions among full-conduit and entrance/exit controlled flow regimes. However the simulator can easily accommodate multiple parallel culverts, and well-established relations for the various culvert flow regimes are available in the literature.

Conclusion

Not too many years ago, a program with CanalCAD's capability would have been the province of expensive and inaccessible mainframe equipment. With the advent of the PC, a huge installed base of very capable machines has evolved, and thus the ability to run CanalCAD is within the reach of nearly all decision makers in the workaday world of irrigation management, operation, and design. CanalCAD was designed from its inception to be a working tool, a workhorse if you will, to aid the irrigation decision maker. As such, it will run on "any" machine that is PC compatible. Clearly, for large canal models and long simulations, a 486 based computer is the minimum configuration; however, CanalCAD will run very well on smaller machines. It is designed so that the computationally intensive routines reside in one place, the simulator; all other program operations, including data input and results viewing, are exceptionally fast, even on very basic hardware. Indeed, much of CanalCAD's development occurred on a notebook 286 with 640k of memory, a CGA monochrome screen, and a 20 megabyte hard disk! It is the hope of the authors that all CanalCAD users--those with modest hardware, as well as users with workstation sized PC's--will find CanalCAD a useful working tool and thus an impetus to implement much needed change in the irrigation systems of our world.

References

Cunge, J.A., Holly, F.M. Jr., and Verwey, A. (1980), Practical Aspects of Computational River Hydraulics, available from Iowa Institute of Hydraulic Research, The University of Iowa, Iowa City, Iowa, 52245, USA.