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CALIBRATION VERIFICATION AND APPLICATION OF A
TWO-DIMENSIONAL FLOW MODEL (U) HYDROLOGIC ENGINEERING
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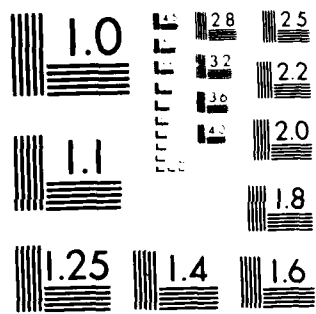
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Calibration, Verification, and Application of a Two-Dimensional Flow Model

by

D. Michael Gee

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Calibration, Verification, and Application of a Two-Dimensional Flow Model

D. Michael Gee* M.ASCE

Abstract

Information was required concerning velocity distributions in the outlet channel immediately downstream from the Harry S. Truman Dam generating facility (see Fig 1). This information was to be used to ascertain hydraulic forces and flow directions for structural design of a fish net or other type of fish barrier to be placed across the outlet channel. The velocity distribution in the outlet channel is complex, governed by operation of various combinations of 1 to 6 pump-turbine units in either generation or pumpback mode. The flow pattern can be further complicated by spillway releases with or without simultaneous operation of the powerhouse. To provide timely design information for the planned fish facilities, a mathematical model was used to predict the flow fields.

Selection of a Mathematical Model

A model for simulation of two-dimensional free surface flows in the horizontal plane was deemed appropriate for this study. The problem was particularly well suited for use of the two-dimensional finite element hydrodynamics model, RMA-2⁽²⁾, which had been used previously by The Hydrologic Engineering Center (HEC) on several project applications.⁽¹⁾

Data Summary

The data required to perform this study may be divided into three categories: (1) "Run" data, i.e. that information required to execute a simulation, (2) "Calibration" data, i.e. prototype measurements which are used to adjust various model coefficients to bring the model's performance into conformance with that of the prototype, and (3) "Verification" data; additional prototype measurements used to evaluate model performance.

Run data were derived from construction drawings of the outlet channel and related physical features. Calibration and verification data consisted of several sets of detailed velocity measurements. Both magnitude and direction of flow velocity were measured at several points in the vertical at several locations across the channel (see Fig 1) for three discharges as shown in Table 1. Values used in this study were averages of the point vertical data at each location.

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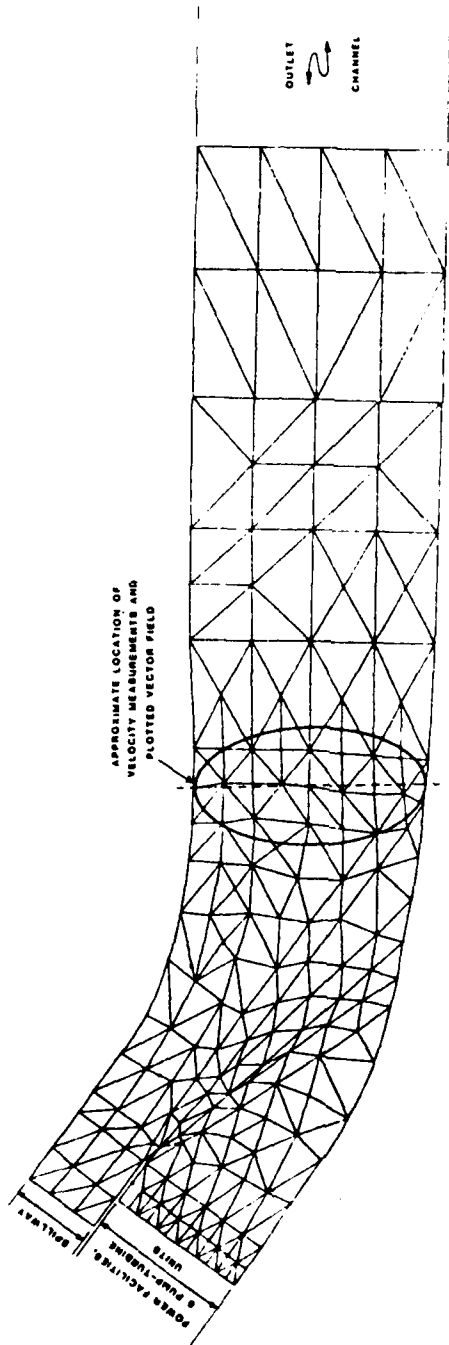


Fig. 1 Schematic Drawing of Study Area
Showing Finite Element Network

TABLE 1. CALIBRATION CONDITIONS

DATE MEASURED	DISCHARGE (cfs)	TAILWATER ELEV (ft. NGVD)	UNITS
5 May 82	27,000	656.0	4,5,6
26 May 82	24,900	658.8	4,5,6
27 May 82	15,280	658.1	4 & 5

Note: 1 cfs = 0.028 m³/s; 1 ft = 0.305 m.

Development of the Finite Element Network/Problem Schematization

The finite element network was developed to provide detail in the area where a fish net was being considered and in areas of anticipated strong velocity gradients. Sufficient network detail was provided at the powerhouse face to resolve flows emanating from individual units. The area schematized extended from the powerhouse face downstream approximately 2700 feet.

The spillway stilling basin was also included in the area modeled as circulations in that area are important to the flow field in general and to allow for simulation of spillway flows if desired. In general, curved-sided elements were used along the flow boundaries to allow tangential flow along the banks. The network used for calibration and production runs is shown on Fig. 1. Note the distinct rows of elements along the possible net alignments; this provides a mechanism for simulating the effect of the fish net on the flow field by increasing the bed roughness within one of these rows of elements to account for head loss across the net. Boundary conditions used were; inflow (generate) or outflow (pumpback) rates at the appropriate units, slip conditions for other flow boundaries, and a prescribed water surface elevation at the downstream boundary. All simulations were of steady state conditions.

Calibration Process/Results

The data obtained on 26 May 82 were used to calibrate the model and the other two data sets used for verification. The measured velocities showed a flow reversal on the left side of the channel with velocities there of up to 1 ft/sec (0.305 m/sec) directed towards the powerhouse. This circulation is apparently driven by flows from the powerhouse persisting as a jet along the right bank. Initial model runs indicated a tendency for the jet to stay on the right side of the channel, however, it diffused and mixed across the channel much more completely than was observed in the prototype. The simulated velocities were in the downstream direction across nearly the entire cross section at the location of the measurement. Use of smaller turbulent exchange coefficients was indicated to decrease mixing in the model. However, when coefficients less than about 15/ft²/sec (1.4m²/sec) were used the Newton-Raphson method used to solve the nonlinear system of equations did not converge.

Boundary roughness is described by the Chezy equation in RMA-2. A Chezy coefficient of 120 ft^{1/2}/sec (66 m^{1/2}/sec) was used; approximately equivalent to a Manning's n of 0.020. Bottom friction does not play a dominant role in this problem, as evidenced by the small head loss in the reach of

interest (this was confirmed by preliminary sensitivity runs). Improvement of the calculated flow distribution by varying the bottom roughness spatially was not attempted because there was no physical justification for doing so.

The initial approach to obtaining a convergent solution with lower turbulent exchange coefficients was to increase network detail. (The initial network contained 228 elements and 509 nodes; the final 313 elements and 686 nodes.) It was thought that this would improve the model's performance for two reasons: (1) increased network detail would allow resolution of smaller scale flow features, and (2) smaller exchange coefficients are usually used with smaller elements. Model performance improved somewhat, but was still unsatisfactory. Attempts were also made to vary the turbulent exchange coefficients in the transverse direction from those in the longitudinal direction. These efforts again did not significantly improve the results.

Convergence of the Newton-Raphson algorithm requires that the first "guess" at the solution be fairly close to the final solution; even for relatively well-behaved functions. The first guess used in RMA-2 is zero velocity everywhere and a horizontal water surface. Provision also exists to use as the first guess the solution from a previously run simulation. HEC had used this feature in a previous study of a situation involving a large change in water surface elevation within the study domain. Successive problems were solved, each having larger water surface gradients and providing the first guess at the subsequent problem solution until the desired problem was solved. It was decided to try this technique by using the convergent solution obtained with large exchange coefficients as the beginning guess for a solution with a smaller exchange coefficients. This technique proved successful in allowing use of exchange coefficients of $7.7 \text{ ft}^2/\text{sec}$ ($0.7 \text{ m}^2/\text{sec}$) which gave a solution that closely matched the observed data (see Fig 2).

The other critical aspect of successfully modeling the H.S. Truman flow field was selection of the depth at the powerhouse. The prototype discharge enters (or exits) over about the lower 2/3 of the tailrace depth and is not uniformly distributed over this portion. As RMA-2 is a vertically averaged model, capturing this vertical detail was not possible. Consequently, proper entrance velocities were obtained by adjusting the bottom elevation at, and immediately downstream from, the powerhouse face.

The model was then tested against the verification data sets (see for example Fig. 3) and produced results equally as good as the calibration run.

Production Runs

Once the model was calibrated and verified, production runs were made. All coefficients and physical characteristics of the model were unchanged from the calibration runs; only inflow locations and quantities and downstream tailwater elevations were changed to model the various operational configurations. To date, fourteen generation and pumpback configurations have been analyzed with the model. The computed velocity fields have provided valuable information for the selection and design of a viable fish facility.

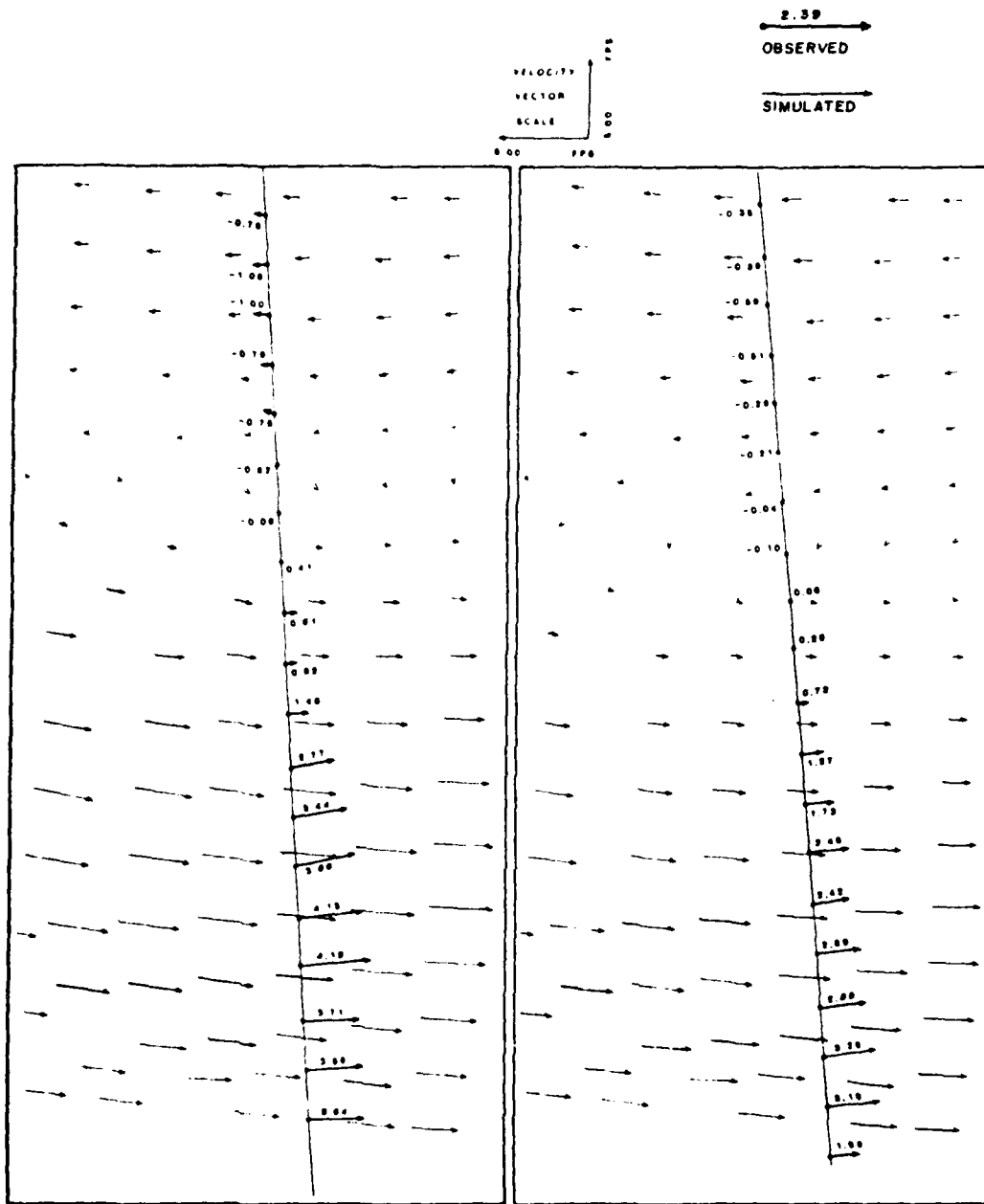


Fig. 2 26 May 82 Observed and Simulated Velocities (Calibration)

Fig. 3 27 May 82 Observed and Simulated Velocities (Verification)

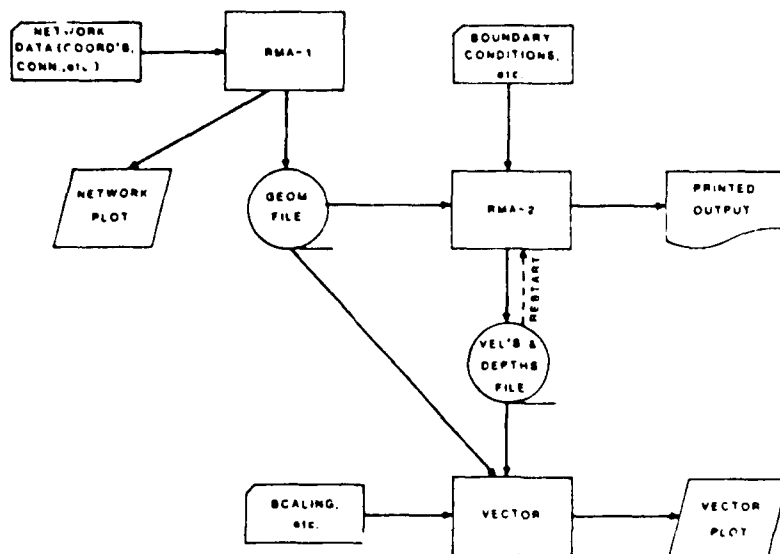


Fig. 4 Data Flow and Program Linkage

Computational Aspects

Performance of this type of study requires manipulation of several data files, application of at least three different computer programs, and graphics capability for analysis of input data and simulation results. The data flow and correspondence between the computer programs are shown on Fig. 4. All simulations were performed on HEC's Harris 500 mini-computer. The RMA-2 simulations required 3-4 minutes of c.p.u. time per iteration, or a total time of about 20 minutes per simulation.

Acknowledgements

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