HYDRAULIC COMPUTATION OF UNSTEADY FLOW IN MUNICIPAL CANAL NETWORK

By

M. Kozák — I. Rátky

Institute of Water Management and Hydraulic Engineering,
Technical University, Budapest

Hydraulic analysis, prediction of flood peaks due to storm in municipal canal systems will be concerned with, considering the simple case of unsteady open canal flow all along in closed-section channels.

Water flow in canalization is from kinematic aspects either:
1. steady, open canal flow;
2. unsteady, open canal flow;
3. steady flow under pressure; or
4. unsteady flow under pressure.

Practically, these water flow types may occur combined.

Actually, only the simple case of gradually varying steady or unsteady open canal flow in closed-section ducts will be considered.

1. Basic equations and solutions of unsteady open canal flow

Regularities of unsteady open canal flow are described by pseudolinear, hyperbolic partial differential equations of the *continuity* type:

$$B \frac{\partial Z}{\partial t} + \frac{\partial Q}{\partial x} = 0 \tag{1}$$

and of the *dynamic* type:

$$\frac{\partial Z}{\partial x} - \frac{Q^2 \alpha'}{gA^3} \frac{\partial A}{\partial x} + \frac{2Q\alpha'}{gA^2} \frac{\partial Q}{\partial x} + \frac{\alpha''}{gA} \frac{\partial Q}{\partial t} + \frac{Q^2}{K^2} = 0 \tag{2}$$

where (Fig. 1):

Z — absolute water level elevation;
Q — water discharge;
B — water surface width;
A — wetted cross section area;
g — gravity acceleration;

K — specific discharge modulus ($kA\,R^{2/3}$)
k — smoothness coefficient
R — hydraulic radius ($R = A/P$)
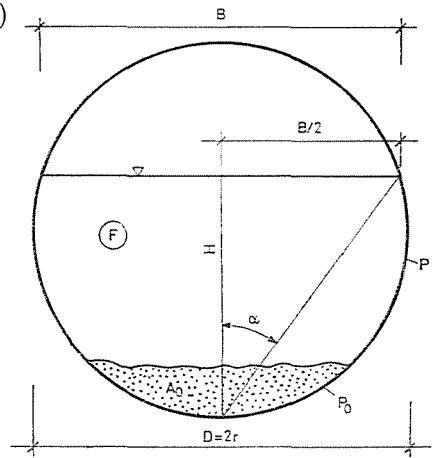P — wetted perimeter;
x — section;
t — time.

Fig. 1. Cross section geometry

The method of characteristics has been chosen for solving Eqs (1) and (2). According to publications, the ordinary differential equation system of characteristics obtained by the determinant method can be solved by approximate numerical integration. The solution requires to give the boundary conditions. Hydraulically, these are initial and boundary conditions.

The *initial condition* means the calculated surface curve of length-wise water discharge distribution in the channel at the initial time t_0. Functions of *initial condition* are:

$$Q = Q(x, t)_{t=t_0}$$

and

$$Z = Z(x, t)_{t=t_0}. \qquad (3)$$

Boundary conditions comprise functions:

$$Q = Q(x, t)_{x=x_{a,f,0}}$$

or

$$Z = Z(x, t)_{x=x_{a,f,0}} \qquad (4)$$

referring to lower, upper and side sections x_a, x_f and x_0, resp., throughout the calculation time-period.

Boundary conditions in the tested urban canalization systems of main and side branches may be:

a) upper and lower sections of the main canal,
b) upper sections of side branches and of secondary side branches and
c) in the manholes.

2. Numerical example

The analyzed canalization system is schematically shown in *Fig. 2*. The system consists of a main canal 2500 m long, a side branch 300 m long, and a side branch 400 m long, joined by another side branch 200 m long. Canals have been divided into elementary lengths $\Delta X = 50$ m. Calculation sections confine elementary lengths, thus, they are spaced at 50 m apart.

Slope, roughness and diameter values of each pipe length have been represented in Fig. 2.
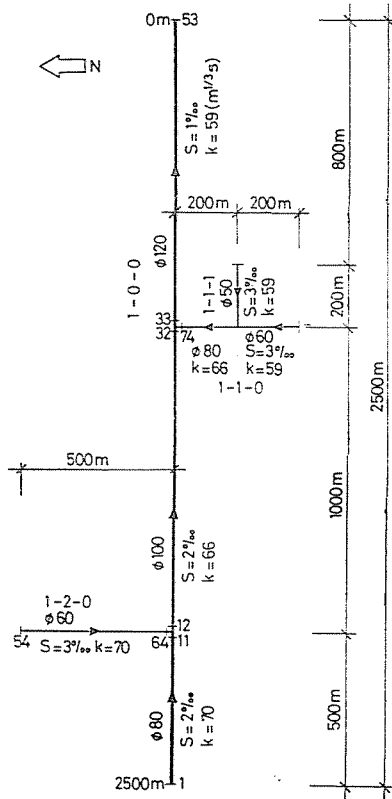

Fig. 2. Layout scheme of the canal system

Hydraulic operation of the canalization system is the following:

At the starting time of computation ($t_0 = 0$), steady, gradually varying flow is assumed to arise throughout the canal system.Thereafter a storm is assumed to inflow across upper sections of side branches, imposing timely variable discharge load. The storm causes a composite wave to flow in the side-branch system. In the presented example, boundary conditions involving just open canal flow have been assumed.

The following calculations are to demonstrate that the same volume of precipitation flowing in the same canalization system and under the same initial condition generates different canal loads depending on the rain front direction compared to the canal system orientation.

The *initial condition* was the same for all computation alternatives. Longitudinal discharge distribution was assumed to be known along the given canal reach surface curve $Z = Z(x)$ was calculated for, in knowledge of the lower water level, assuming steady, gradually varying flow. Assumed discharges and calculated surface curves (backwater curves) are presented in Fig. 3.

Boundary conditions: rainfall loads of different flow directions in upper sections of main canal and side branches were simulated by Q-t diagrams starting at different times. To ease comparison, loads were the same in each tested
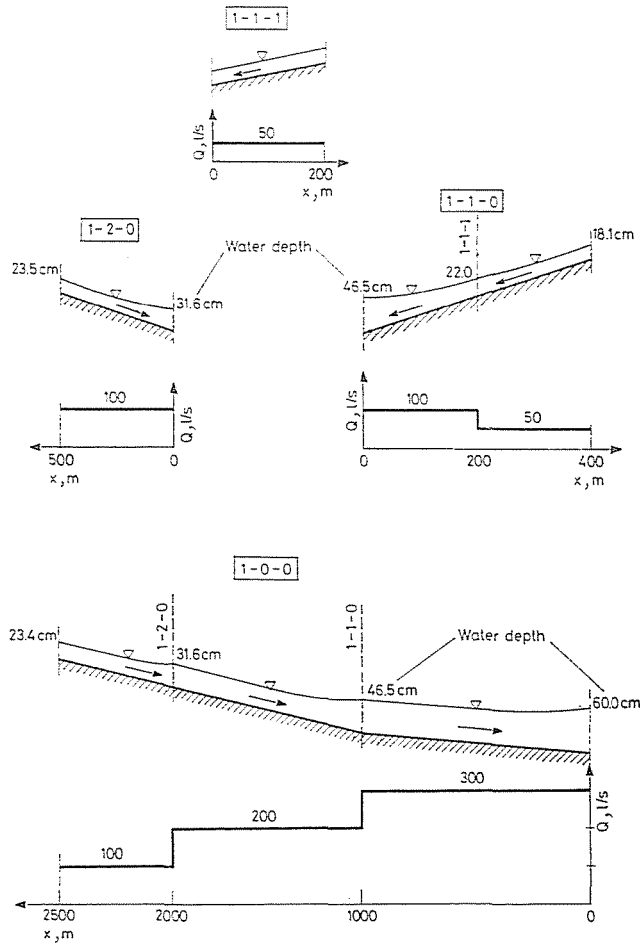

Fig. 3. Characteristic curves $H = H(x)$ and $Q = Q(x)$ of the initial condition

alternative. A canalization system oriented as seen in Fig. 4 was assumed, and loads due to rainfall fronts proceeding in N—S, S—N, E—W and W—E directions and to standing precipitation were tested. Precipitation advancement was simulated e.g. in N—S direction by loading branch 1—2—0 first, then main canal 1—0—0, thereafter secondary side branch 1—1—1, and finally, side branch 1—1—0 (see Fig. 4). Rainfall front travels crossing the main canal from the left to the right, of the same, and of opposite directions could be similarly simulated by rainfall loads starting at different times. The load due to standing precipitation started at the same time in every section under boundary condi-
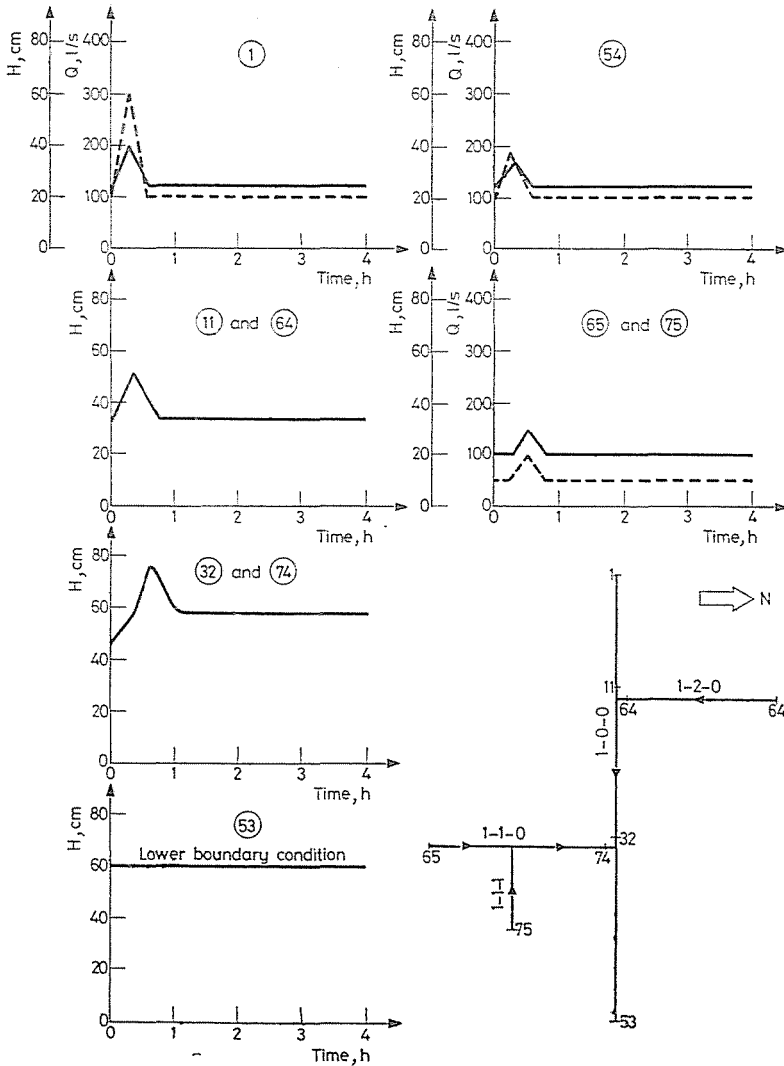

Fig. 4. Calculated characteristic curves $H = H(x)$ in case of an $E—W$ rainfall front. —— H (cm) water depth; - - - Q (l/s) discharge boundary conditions

tion. For the main canal section joining the inlet a boundary condition $Z = $ const. was assumed.

From among computation results, variations of water depths H and of discharges Q vs. time T were examined in the most typical cross sections. Here only diagrams of the consequences of rainfall fronts proceeding E—W and W—E will be presented in Figs 4 and 5. In comparing alternatives, primarily their deviation tendency was examined. Deviations are of absolute low value, the system being of rather small extension to spare running time. The criterion of open flow keeps rainfall loads low.
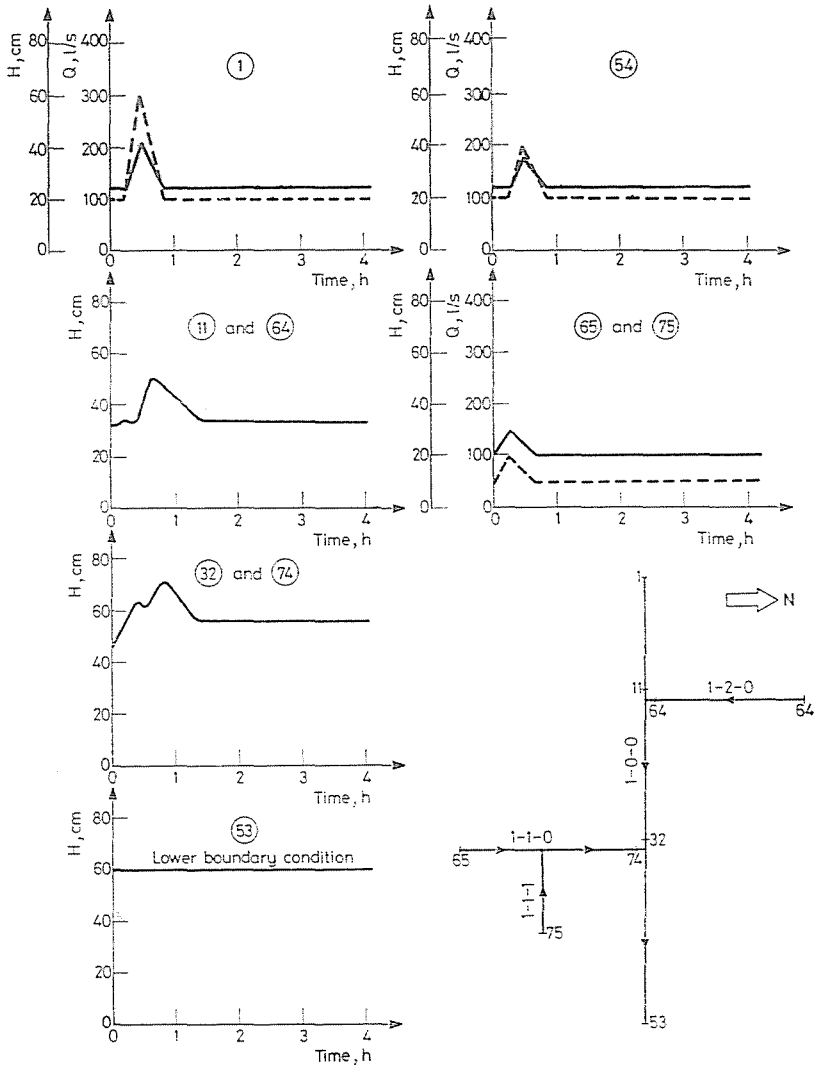

Fig. 5. Calculated characteristic curves $H = H(x)$ in case of a W—E rainfall front. —— H (cm) water depth; - - - Q (l/s) discharge boundary conditions

Computation results have led to the following conclusions:

1. Unsteady open canal flow in urban canal systems is accessible to calculation, and engineering experience rather than convincing measurements suggests results to be physically realistic.

2. Precipitation front in the main canal flow direction (W—E) causes the biggest load (fullmess) in the canal system, due to wave superposition. Let us consider e.g. section 32 (main canal section upstream the mouth of side branch 1—1—0). In the case of a W—E rainfall front, the load from the upper catchment 1—1—0 (Fig. 5), while in case of an E—W the rainfall front opposite to the flow direction, the main canal load is superposed to the ebbing branch of side-branch load in section 32 (Fig. 4). This latter case is, of course, one of lesser peak load water depth (fullness).

3. From the aspect of discharge canal fullness a S—N rainfall front is the best.

4. In case of a standing rainfall front, discharge is worse than either those of S—N or of N—S direction, even water depths exceeding that for E—W arise. Maximum water depths between sections 32 and 53 are about averages of maximum water depths for rainfall fronts of directions E—W and W—E.

3. Future research objectives

The presented computation method suits water flow in canal system only in the simplest case (open canal flow). Proposed major research programs are, in short:

1. Development of a computation method for flow under pressure (partly accomplished [2]).

2. Consideration of the effects of local losses (hydraulic structures, bottom weirs etc.) and of the storage capacity of shafts. Physical model tests.

3. Special study on the practical computation of precipitation loads.

4. Analysis of the effect of underground sewage water reservoirs, peak-smoothing spillways, pump station, in complexer systems connections between side branches, insertion of relieving canal reaches etc.

5. Data needed for the restoration or operation have to be optimized by systems engineering analysis for the design of a network, or indicated by optimum forecasting for the reconstruction of old ones.

6. In possession of hydraulic values inside the channel, the mathematical model is easy to extend to the sewage concentration variation.

Conclusion

A new method has been developed for unsteady flow in municipal combined sewage canal system. A numerical example has demonstrated rain front in motion to cause different loads (fullnesses) — even in the considered simple

case — depending on the direction of front advancement compared to the main canal. Further theoretical research is suggested to improve accuracy and simulation truth.

This computation method offers the following advantages and possibilities:

— flow change with time to take canal storage capacity into consideration;
— arbitrary variation of boundary conditions from surface flow for each shaft with time;
— a peak-smoothing reservoir of arbitrary operation and size, to be connected anywhere to the canalization system;
— suitability of the computer program to compute an infinity of canal design alternatives with different geometries, situations and hydraulic characteristics (sectional dimensions, silting rate, slopes, shaft spacing, situation, size and operation of reservoir(s), etc.).

Summary

A new method has been developed for unsteady flow in municipal combined sewage canal systems. A numerical example has demonstrated rain front in motion to cause different loads (fullness) — even in the considered simple case — depending on the direction of front advancement compared to the main canal. Further theoretical research is suggested to improve accuracy and simulation truth.

This computation method offers the following advantages and possibilities: flow change with time to take canal storage capacity into consideration; arbitrary variation of boundary conditions from surface flow for each shaft with time; a peak-smoothing reservoir of arbitrary operation and size, to be connected anywhere to the canalization system; suitability of the computer program to compute an infinity of canal design alternatives with different geometries, situations and hydraulic characteristics (sectional dimensions, silting rate, slopes, shaft spacing, situation, size and operation of reservoir(s), etc.).

References

1. Kozák, M.: Computation of Open-Surface Unsteady Water Flow*. Akadémiai Kiadó, Budapest, 1977.
2. Kozák, M.—Bakonyi, P.—Horváth, L.—Rátky. I.: Computation of Unsteady Flow in Municipal Storm Sewer System. IAHR Conference Bratislava, May 4—8, 1981.
3. Kirshen, P. H.—Marks, D. H.: Screening Model for Storm Water Control. Proc. ASCE, E. E. 4. Aug. 1974.
4. Abott, M. B.—Harno, K.: A Modelling System for the Design and Operation of Storm Sewer Networks. IAHR Conference Bratislava, May 4—8, 1981.
5. Holly, F.—Cheverean, G.—Mazaudon, M.: Numerical Simulation of Unsteady Flow in Storm Sewer Systems Using Complete and Simplified Flow Equations. IAHR Conference Bratislava, May 4—8, 1981.

Prof. Dr. Miklós Kozák, Head of Dept., Director ⎫
Senior Assitant Dr. István Rátky   ⎬ H-1521, Budapest
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* In Hungarian.