A Java-based Program for Numerical Computation of Hydraulic Shock

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Abstract: Numerical solving, by method of characteristics, of the hydraulic shock problem required to develop a computer program that automatically respond to the following requirements: easy management of several projects, easy introduction, editing and change of data entry, and proper display of the program output: the hydraulic load and speed for every moment of time. The program is written in Java programming language. The calculation was done to study the phenomenon of hydraulic shock in the following schedule: pump - pipeline - tank (PCR) without changing the section of heading pipeline; tank - pipe - valve (RCV) for a section of the pipeline; tank - pipe - valve (RCV Complex) with changing cross-section of pipeline. The output refers to the values of speeds and hydraulic loads of the sections along the pipeline, elements that can assess system behavior in a given situation.

Key-Words: hydraulic shock, flowchart, graphical interface

1 Introduction

The movement of fluids in unstationary state is a normal case in the functioning of hydraulic installations. Due to the changes in time of the hydraulic parameters on the pipe extremities or due to the handling of valves located somewhere in the pipe, the unstationary state appears in a pressure pipe. Examples of situations when the unstationary state appears: the water enters (exits) in (out of) a pipe from (in) a tank whose level is meanwhile amended, water is pushed into the pressure pipe by a centrifugal pump while the pump speed changes, water pipeline triggers a turbine rotor which the regulator flow turbine changes over time etc.

Moving from one operating system to another is pretty quick, through a transitory movement, which is due to changes of operating conditions existing in one or more points in the system.

In a transitory state, the movement of fluids may be slow or fast variable, depending on the disturbance and initial conditions, on the characteristics of fluid elasticity and the hydraulic system itself, and on the protection devices.

Typically, in the pressure pipes the rapid variable movement of liquids is called water hammer or hydraulic shock. In the water hammer (hydraulic shock) phenomenon analysis the fluid compressibility and elasticity of pipe wall must be taken into account. Otherwise (liquids and walls are uncompressible), kinetic energy of the liquid mass is transformed abruptly into mechanical work, in conditions of virtually zero travel. In these circumstances, the forces and pressures are extremely high.

The faster, the closure and the longer the pipe, the more violent the water hammer phenomenon is. On the contrary, the water hammer phenomenon is lower in short pipes, when the maneuver of valves is slow or when a part of the pipe has the capacity to accumulate the liquid or when the liquid finds its way out through a leak in the pipeline.

The water hammer is an overpressure (alternating positive and negative) added to the pressure from the steady movement and independent from this pressure. Therefore the study of impermanent operating system is very important and is, in most cases, a necessary condition for the proper design of a hydraulic system and its operation.

2 Mathematical model

Currently, the method of characteristics is the most widely-used method in the practical calculus of hydraulic shock by numerical simulation.

There are some advantages of this method. Among the advantages we mention:
- the accuracy of calculations is higher than the other methods, by keeping into account the terms with small share equations of motion;
- it's easier to handle the limit conditions and to program the complex pipes;
- loss of hydraulic load can be concentrated or uniformly distributed, showing the easer handling of the limit conditions.

This method presents a single disadvantage: the access to a computer system is necessary, so knowledge of a programming language is required.

The fundamental equations of water hammer phenomenon are:
- continuity equation

$$\frac{dh}{dt}+\frac{c^2}{g}\frac{dv}{dx}+\frac{\lambda v|v|}{2gd}=0 \qquad (1)$$

- dynamic equation

$$\frac{dh}{dx}+\frac{1}{g}\frac{dv}{dt}=0 \qquad (2)$$

where: v is speed, h-hydraulic load, c-celerity, g-gravity acceleration, $\frac{\lambda v|v|}{2gd}$ - the friction.

The equation (1) and (2) may be replaced by two systems of equivalent ordinary differential equations:
- for direct characteristic curve:

$$C^+\begin{cases}\dfrac{dh}{dt}+\dfrac{c}{g}\dfrac{dv}{dt}=0\\[2mm] \dfrac{dx}{dt}=c\end{cases} \qquad (3)$$

- for the reverse characteristic curve

$$C^-\begin{cases}\dfrac{dh}{dt}-\dfrac{c}{g}\dfrac{dv}{dt}=0\\[2mm] \dfrac{dx}{dt}=-c\end{cases} \qquad (4)$$

If the friction is taken into account, relations (3) and (4) become:

$$C^+\begin{cases}\dfrac{dh}{dt}+\dfrac{c}{g}\dfrac{dv}{dt}+\dfrac{c}{g}\dfrac{\lambda v|v|}{2d}=0\\[2mm] \dfrac{dx}{dt}=c\end{cases} \qquad (5)$$

and

$$C^-\begin{cases}\dfrac{dh}{dt}-\dfrac{c}{g}\dfrac{dv}{dt}-\dfrac{c}{g}\dfrac{\lambda v|v|}{2d}=0\\[2mm] \dfrac{dx}{dt}=-c\end{cases} \qquad (6)$$

To solve numerically the systems for a simple (ordinary) pipe (5) and (6), the length of pipe is divided into N equal sections, the length is $\Delta x=\frac{l}{N}$ and the time is $\Delta t=\frac{\Delta x}{c}$.

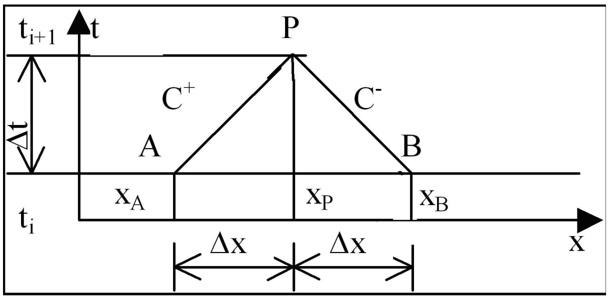

Fig. 1 Defining characteristic curves

Integrating the equation (5), along direct characteristic C^+ between two points A and P (Fig. 1) we obtain:

$$\int_{h_A}^{h_P}dh+\frac{c}{g}\int_{v_A}^{v_P}dv+\frac{c\lambda}{2gd}\int_{t_A}^{t_P}v|v|dt=0 \qquad (7)$$

which becomes:

$$h_P-h_A+\frac{c}{g}(v_P-v_A)+\frac{c\lambda}{2gd}v_A|v_A|\Delta t=0 \qquad (8)$$

The second equation of the system, (6), acquires the form:

$$x_P-x_A=c(t_P-t_A) \qquad (9)$$

Similarly, for the reverse curve we obtain the following relations:

$$h_P - h_B - \frac{c}{g}(\mathrm{v_P} - \mathrm{v_B}) - \frac{c\lambda}{2gd}\mathrm{v_B}|\mathrm{v_B}|\Delta t = 0 \quad (10)$$

$$x_P - x_B = -c(t_P - t_B) \quad (11)$$

Using equations (9) and (11) for the entire pipe, by dividing it into sections for calculation we obtain a network of features, which provides solutions to equations in each node of the network (Fig. 2). We start from known initial conditions for $t = T_0$, so we know the values of h and v in all sections of calculation, specifying the time of calculation and using the relations (9) and (11), the characteristic lines that pass through the initial sections are crossing in other sections.

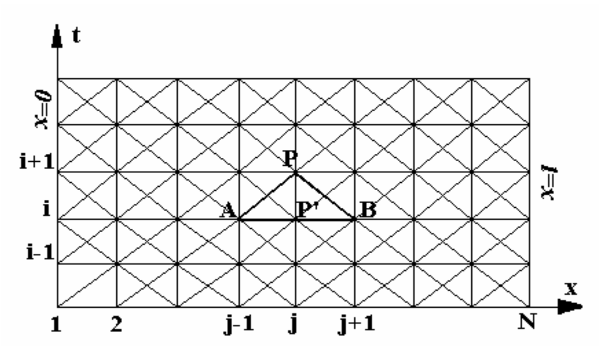

Fig. 2 Rectangular network characteristics

With the scheme from Fig.2, for calculating the speed and hydraulic load in any section j, and solving the equations (8), (10) and we get:

$$\mathrm{v}_{j,i+1} = \frac{1}{2}\left[v_{j\text{-}1,i} + v_{j+1,i} + \frac{g}{c}\left(h_{j-1,i} - h_{j+1,i}\right) - \right.$$
$$\left. - \frac{\lambda \Delta t}{2d}\left(v_{j\text{-}1,i}\left|v_{j\text{-}1,i}\right| + v_{j+1,i}\left|v_{j+1,i}\right|\right)\right] \quad (12)$$

respectively

$$h_{j,i+1} = \frac{1}{2}\left[h_{j\text{-}1,i} + h_{j+1,i} + \frac{c}{g}\left(v_{j-1,i} - v_{j+1,i}\right) - \right.$$
$$\left. - \frac{c\lambda\Delta t}{2gd}\left(v_{j\text{-}1,i}\left|v_{j\text{-}1,i}\right| - v_{j+1,i}\left|v_{j+1,i}\right|\right)\right] \quad (13)$$

With these relations we calculate quantities v and h, step by step in all sections at the j and i +1, depending on the corresponding known sizes of the preceding i. The initial data of the problem are used for the first step of calculation. Using numerical methods for calculating virtually water hammer, Courant condition must be used in the following form:

$$\Delta t \le \frac{\Delta x}{c} \quad (14)$$

3 Presentation of the calculation

The presentation of the solutions of hydraulic shock problem, using numerical calculus by means of the characteristics method discussed in this paper, show the need for the development of a computer program that automatically responds to the following requirements:

- easy management of several projects
- easy introduction, editing and modification of data entry.
- proper display of the program output: the hydraulic load and speed every moment of time.

The program is written in Java programming language. The calculation was done to study the phenomenon of hydraulic shock in the following scheme:

- pump - pipeline - tank (PCR) without changing the section of the repression pipe;
- tank - pipe - valve (RCV) for a section of the pipeline;
- tank - pipe - valve (RCV Complex) changing the cross-section of the pipeline.

The existing data refer to the speed and hydraulic load values in sections along the pipe, by means of which we can appreciate the behavior of the system in a given situation. To solve the already mentioned objectives, the program was designed according to the logical schema in Fig.3.

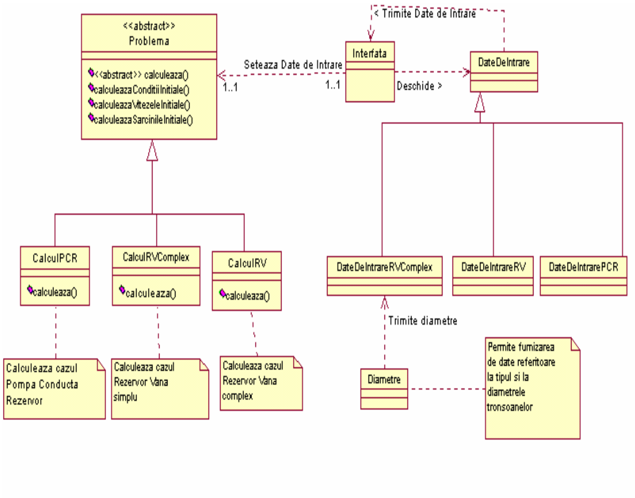

Fig. 3 Logical schema

Graphical interface (Fig.4), which shows how easy is to use computer program, was programmed in Java.

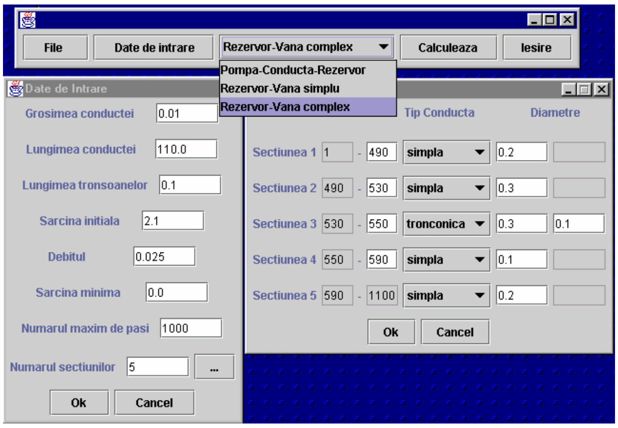

Fig. 4 Graphical interface

4 Numerical application

We consider a pumping installation with the follow parameters: Hg =30 m - the geodesic height, D = 0,6m - the diameter of pipe, Q = 0,848 m^3/s - the pumping flow, n = 0,012 - the roughness coefficient, Δx - the length of the calculus section. It is considered an accidental closing of the check ball and the closing time of the check ball is 0,1 seconds. The maximal pressure in the section situated near the pump and the time which corresponds to the maximal pressure, in the situation without protection, is 248 mH_2O.

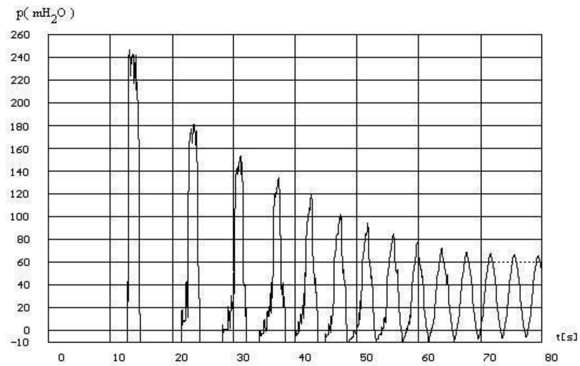

Fig. 5 Variation of pressure in time

5 Conclusion

The application allows the user to execute quickly and efficiently a complex algorithm over a large data set, having the results calculated in a short period of time (depending of the user computer resources) and registered in a text file in a specified location.

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