Computer processing and simulation results of hydraulic experiments in the gravity pipelines and their protective coatings used in the construction and reconstruction of water disposal systems

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Abstract. On the basis of the known hydraulic dependences, which describe the fluid flow regimes in gravity pipe lines, the results of bench experimental studies on various types of pipeline materials and internal protective coatings have been analyzed in an automated mode. The simulation technique algorithm and the automated program are constructed in such a way as to be a kind of experiments' catalogue (database) carried out on a universal hydraulic bench. The program content and the requirements to input and output information are presented herein. The results of an automated processing of the experimental data are given in the form of tables and graphical dependences, which characterize the liquid gravity flow regime depending on the degree of the pipelines roughness made of different materials. The target of the program is to provide a wide application of its results by the designers as tool in their design works when designing gravity water discharge lines, as well as in construction, modernization and renovation of pipeline transport facilities focusing on the trenchless repair methods. The program has a special unit, which assesses and compares domestic and foreign methods of hydraulic calculations of pipe lines through the roughness coefficients determined by the formulas of Manning and N.N. Pavlovskiy.

1. Introduction

Pipelines of water discharge systems, which are subjected to trenchless repair works through application of various internal protective types coatings in the form of pipes or thin-walled hoses (shells), are characterized by a number of indices, which primarily include their strength and hydraulic characteristics [1, 2]. Various types of sprayed composite materials are also used as repair materials, which can be a localization effective mean of pipeline system defects, such as cracks, fistulas, joint discrepancies, etc. [3, 4]. When decrepit pipes have to be replaced by a traditional procedure by digging pits or destruction of dilapidated lines by trenchless methods, use may be made of the pipes manufactured of new materials, so their hydraulic performance must be determined experimentally [5, 6]. Thus, it can be stated, that the study of hydraulic characteristics of protective coatings types is currently relevant. It also follows from this, that to enable a skilled performance of design works the researchers and engineers have a mandatory obligation to determine hydraulic characteristics of pipes and protective coatings made of new materials using special benches [7, 8].

The chairs of «Water supply and water discharge» and «Applied Mathematics» of Moscow State University of Civil Engineering proceeded to some research works on program development of initial

data automated processing and receiving design mathematical dependences and hydraulic parameters of pipes new types and protective coatings, when the experiments are performed on gravity hydraulic benches [9, 10]. The algorithm (technique) was aimed at analyzing the results of experiments and constructing graphical dependences, that characterize the gravity flow regime depending on a number of factors, in particular, the degree of pipelines roughness made of different materials. The continuation of this theme helped to create an automated calculation program [11] to determine such parameters as the Chézy coefficient C and relative roughness «n» according two alternative formulae used in domestic (N.N. Pavlovskiy formula) and foreign (Manning formula) practices. In addition, a new bench test is developed to study the turbulence and the transfer capacity of a liquid flow by optical means in open trays having different relief of their internal surfaces [12].

2. Materials and methods

By omitting the methods essence of conducting the gravity pipe line hydraulic studies on long benches with the appropriate set of tools and instrument base, the mathematical processing of the experimental results consisted in execution of several consecutive operations.

1). Determination of pressure losses along the length h by an experimental method and calculation of the hydraulic friction coefficient λ according to Darcy–Weisbach formula (1):

$$h = \frac{\lambda l}{4R} \cdot \frac{v^2}{2g},\qquad(1)$$

where λ is the coefficient of hydraulic friction; g is acceleration of gravity, m/s^2; R is the hydraulic radius, m; V is liquid flow velocity, m/s; l is the length of the experimental plot (in the performed experiments the length made 10 m).

The value h is the difference in the readings of piezometers, i.e. between the first P_1 and the second P_2 in the course of flow taking into account the height difference Δh^i in relation to the comparison plane, and is determined by the formula (2):

$$h = P_1 - P_2 + \Delta h^i \qquad(2)$$

The values of the hydraulic radius R and the flow velocities v shall be calculated through the velocity pressure head $V^2/(2g)$ and the filling h_t/d_t (where h_t is the height of the water layer; d_t is the diameter of the pipeline).

2). The values of the average velocity pressure head shall be made according to the formula (3):

$$\left(\frac{V^2}{2g}\right)_c = \left[\left(\frac{V^2}{2g}\right)_1 + \left(\frac{V^2}{2g}\right)_2\right]/2 = (\frac{Pt_1 - P_1}{2}) + (\frac{Pt_2 - P_2}{2}) \qquad(3)$$

Here the readings of Pitot tubes Pt at the beginning and at the end of the experimental plot Pt_1 and Pt_2 have been marked respectively.

3). Taking into account the actual length of the experimental plot $l = 10$ m, the calculation of the hydraulic friction coefficient λ is made by converting the basic formula (1) and the formula (2) to the formula (4):

$$\lambda^i = \frac{4R_c h^i}{l(\frac{V^2}{2g})_{\tilde{n}}} = 0{,}8R^i_c(\frac{P_1 - P_2 + \Delta h^i}{Pt_1 - P_1 + Pt_2 - P_2}) \qquad(4)$$

The values of the hydraulic radius R shall be taken in m, and the readings of the piezometers and Pitot tubes in cm.

4). The calculation of average filling values $(h_t/d_t)_c$ at the beginning and the end of the experimental plot, as well as the average hydraulic radius Rc shall be made taking into account the

piezometer readings according to the formulae (5) and (6), where the formula (6) binds, in particular, the value of the hydraulic radius and of the filling according to the known chart of hydraulic radius – filling dependence [13, 14]:

$$(h_t / d_t)_c = \left(\frac{P_1 + P_2}{2d_t} \right) \tag{5}$$

$$R^i_{\ c} = 0{,}01 \cdot 0{,}4215 \cdot d_t \left(\frac{P_1 + P_2}{2d_t} \right)^{0{,}7884} \tag{6}$$

The values of the hydraulic radius are taken in m (for this, a conversion factor of 0,01 is adopted), and the piezometer readings - in cm.

5). The Chézy coefficient C shall be calculated according to the formula (7):

$$C = \sqrt{\frac{8g}{\lambda}} \tag{7}$$

The Chézy coefficient C shall be measured in $m^{0{,}5}$/s.

The algorithm of the automated program provides plotting of two graphical dependencies types $C=f(R)$ and $C=f(I)$ for a wide range of slopes I. The algorithm also provides calculation of the relative roughness coefficient «n» on the basis of the formulae comparison, which has been got at the result of the experience, and these ones of Manning and N.N. Pavlovskiy, which are widely used in the practice of pipeline designing, for determination of the Chézy coefficient C through the formulae (8, 9):

- according to Minning:

$$C = \frac{R \cdot 0{,}1667}{n} \tag{8}$$

- according to N.N. Pavlovskiy:

$$C = \frac{R^y}{n} \tag{9}$$

The y exponent shall be determined according to the formula (10):

$$y = 2{,}5 \cdot n^{0{,}5} - 0{,}13 - 0{,}75 \cdot R^{0{,}5} \cdot (n^{0{,}5} - 0{,}1) \tag{10}$$

Here with the essence of operations on determination of the relative roughness coefficient n is reduced to equating the values of the Chézy coefficient C got from the experience to these ones obtained by the formulas by Manning and N. N. Pavlovskiy under the corresponding design fillings and thus getting the relative roughness through calculations.

When calculating the roughness coefficient n by an automated mode, the following operations have to be performed:

- from a number of given dependences the user chooses an optimal one $C=f(R)$, for example, the exponential dependency $C=64{,}766 \cdot R^{1{,}7572}$, and proceeds to its transformation for conformity to the well-known formulae of Manning and N.N. Pavlovskiy;
- solution of two n equations in an automated mode:
  a) according to Manning: $64{,}766 \cdot R^{1{,}7572} = R^{0{,}1667}/n$, then $n = R^{0{,}1667} / (64{,}766 \cdot R^{1{,}7572})$
  b) according to N.N. Pavlovskiy: $64{,}766 \cdot R^{1{,}7572} = R^y/n$,

The exponent is determined according to the formula (10).

As it follows from the formula (10), the equation that uses the N.N. Pavlovskiy dependence, is transcendent, i.e. n is present in the right and left parts of the equation. To find n, a standard method of the half division is used by the automated program.

APCSCE

IOP Conf. Series: Materials Science and Engineering 456 (2018) 012024

IOP Publishing

doi:10.1088/1757-899X/456/1/012024

The automated program developed by the authors is designed in such a way as to serve a kind of catalog (database) of all experiments performed on a universal hydraulic bench for hydraulic properties investigation of gravity pipelines (protective coatings) made of various materials to be used in case of a trenchless renovation of dilapidated gravity networks of water discharge systems. When displaying data on the screen, the program includes, as a basic information, three tabs almost corresponding to three dialog boxes (Figure) with control lines located in the lower part of the output forms.

The dialog boxes are located in a certain sequence: the first dialog box is the «Conditions of the experiment»; the second one is the «Experimental Data» and the third one is the «Output form» (see Figure).
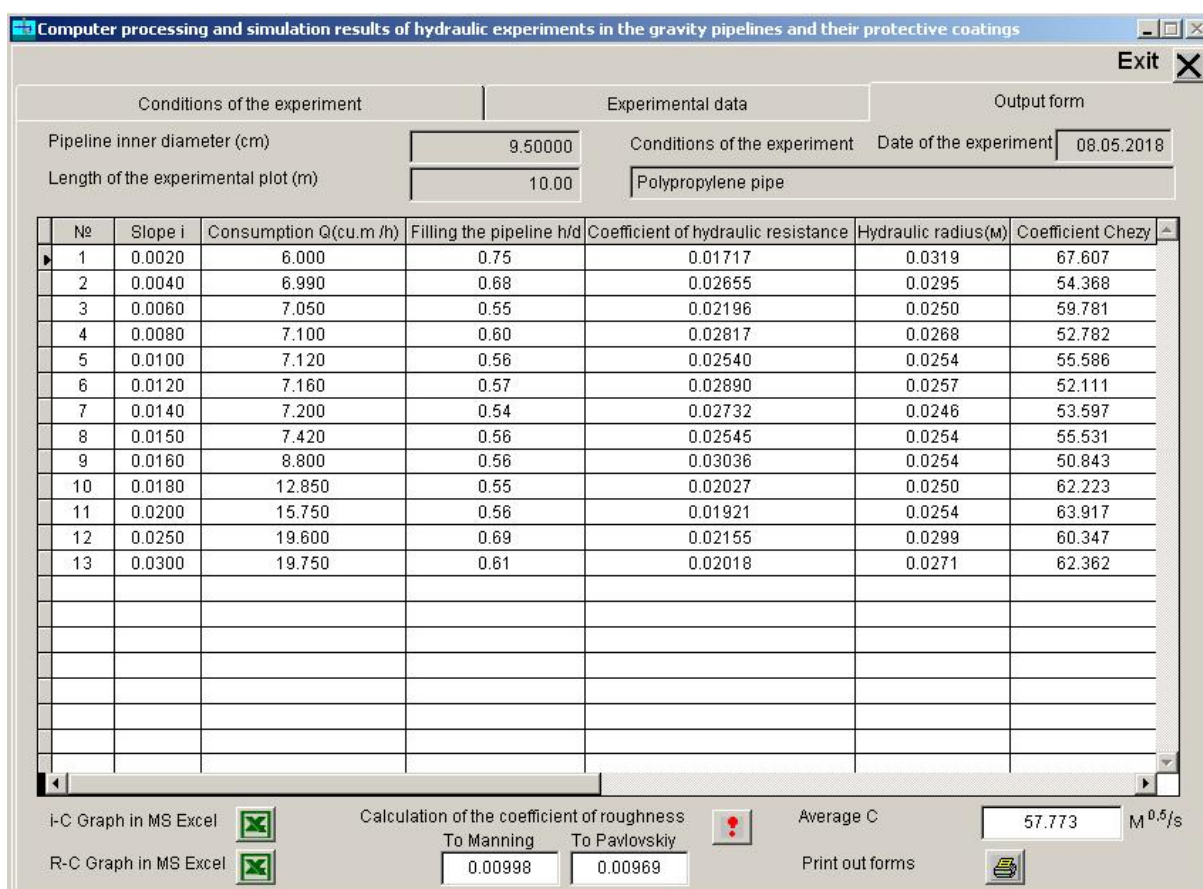

Figure. The tab «Output form».

The User Guide includes the following operations:

1) The program is launched using the appropriate file, resulting in a general view with information on the first tab «Conditions of the experiment». Here the directory is shown with initial and calculated data, which is got in the result of processing the preceding information. Then provision is made of introducing the experiments corresponding data of the «Condition of performance» (the name of the pipe), the inner diameter of the pipeline and the length of the experimental plot. To save the entered information the «Save» button shall be pressed. After that, the further activity is carried out under the assigned code personal number. If any typing error or failure occurs, the button «Cancel» shall be pressed, and all information with the appropriate code will be withdrawn.

2) When pressing the button of the second tab «Experimental data», the initial information about the slope, consumption, readings of the piezometers and Pitot tubes are entered line by line.

3) When you click on the button of the third tab «Output form», a table appears, which presents all initial and calculation information within the performed experiment with a personal code number. The program allows construction of the slope *I* and the hydraulic radius *R* dependencies from the Chézy coefficient *C*. There are rows under the table with the buttons «I-C Graph in MS Excel», «R-C Graph in MS Excel», «Calculation of the coefficient roughness according to Manning and to Pavlovskiy» with zeroed preliminary values. To the right of the boxes there is a red button with an exclamation point! «Average C», and in the lower right corner there is a button «Print output form» (see Figure 1). When this button is pressed, all input and calculation information is shown on the screen and may be printed, if necessary. Also, when the user clicks on the button «I-C Graph in MS Excel» or «R-C Graph in MS Excel», four types of curves appear, which have to be analyzed manually. As a result, the dependence with maximal degree of convergence of the results shall be chosen.

After selecting the dependence, the «Exclamation point» button is pressed, and the «Output form» appears on the display screen with «n» specific design values according to Manning and N.N. Pavlovskiy. In order to have such design data, a designer is able to make a better selection of the appropriate repair materials (based on the assessment of the roughness coefficient), as well as the degree of hydraulic compatibility of decrepit and restored parts of the water discharge pipeline.

3. Results and discussions

There is an example below of the automated program use, that enables determination of the relative roughness coefficient of the WAWIN pipes, which are a novelty in the practice of this country, i.e. a polypropylene corrugated pipe (with the inner diameter of 9.5 cm) and a smooth pipe (with the inner diameter of 10.4 cm) made of non-plasticized polyvinyl chloride (PVC).

Based on the field experiments results in an automated mode, when the design filling made 0.6, the relative roughness *n* for the first pipe made: $n_1 = 0.00998$ (according to Manning formula) and $n_1=0,00969$ (according to N.N. Pavlovskiy formula). The data, which are similar to the given ones, have been got for the second pipe: $n_2= 0.00939$ (according to Manning formula) and $n_2 =0.00925$ (according to Pavlovskiy formula). As it follows from the presented data with regard to the roughness, the discrepancy with the results of two formulas made no more than 3.0 %, which is acceptable for such engineering calculations. The experiments with other pipes also confirmed a slight difference in the values of the degree of roughness determined by the two formulas.

If we compare the values *n* with the relative roughness value of the most commonly used ceramic pipes in the drainage systems $n_k =0.0134$, it can be noted that the roughness of the pipes under investigation is much smaller. It greatly distinguishes them in terms of the hydraulic resistance during the liquid flowing. Thus, hydraulic calculations of water discharge pipelines according to the Manning formula (at the design filling of the pipeline), the Chézy coefficient *C* for the pipes under investigation can be defined for the relevant filling (hydraulic radius) using the formulas (11, 12):

$$C_1 = \frac{1}{0,00998} \cdot R^{1/6} = 100,2 \cdot R^{1/6} \tag{11}$$

$$C_2 = \frac{1}{0,00939} \cdot R^{1/6} = 106,5 \cdot R^{1/6} \tag{12}$$

The performed experiments and the operational automated processing of the results are consistent with the ongoing studies on simulation of gravity water discharge pipe lines during their repair and checking hydraulic calculations [15], as well as optimization of renovation works planning of regional water discharge systems [15, 16].

4. Conclusions

- Theoretical provisions of hydraulic calculations sequence, the structure and the application procedure of an automated program aimed at the experimental data processing when conducting field experiments on gravity pipelines of different roughness are presented herein.

Besides, there are given possible features of the program to obtain the desired mathematical dependences and simulation of hydraulic performances.

- A specific example shows the calculation procedure of the roughness coefficients for two types of pipes and the calculation results' analysis according to Manning and N.N. Pavlovskiy formulas. A slight difference of the design pipe roughness values according to formulas allows us to consider them as interchangeable ones.

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