Hydraulic calculation and design of no-dig recovered pipelines

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Abstract. The research of hydraulic properties of pipes to be relayed in repair bays or to be no-dig recovered is a constituent part of renovation approach. The designers do not have any information on hydraulic properties of new protective materials and have to use the hydraulic calculations procedures, strength and hydraulic data submitted by pipe manufacturers that may not be regarded as objective arguments towards selection of pipeline material. Role of experimental hydraulic studies is increasing therewith. One must have information on hydraulic properties of both pipes and repair materials (e.g. polymer covering, new types of polymer pipes, etc.) to analyze the situation. Two polymer pipes that can be used for trenchless renovation are considered and analyzed: corrugated polypropylene pipe DN 98 and bare pipe DN 105 made from unplasticized polyvinyl chloride. The experimental results to fix relative roughness factor are presented and analyzed in this paper.

1 Introduction

Current trends in wide application of new pipes made from different materials (including the synthetic ones) during repair and modification of old networks being destroyed result in using different pipes of materials for drainage system from year to year thereby making it difficult to evaluate hydraulic data and operation thereof, because each pipeline section is to be appropriately served (e.g. pipe cleaning, etc.) [1-5].

Nowadays there are no strict hydraulic dependencies of Chezy coefficient C and pipe friction number λ for pipelines made from new materials. Furthermore, actually each pipe manufacturer gives its own nonobjective evaluation criteria for different pipe compatibility. The problem is more aggravating with increase of new materials usage, with each of them being applied in repairing non-pressure network, thus resulting in some sort of a network with “patches”. It may also result in hydraulic unbalance i.e. possible negative tendencies due to flooding in pipe junctions or in certain distance from junction points [6-10].

Many scientists (Prandtl L., Chezy A., Bazen A., Manning R., Pavlovsky N.N., Altschul A.D., Yakovlev S.V., Dobromyslov A.Ya., Kalitsun V.I., Kurganov A.M., Lukinych N.A., Fedorov N.F. etc.) were engaged in problems of hydraulic calculations and designing non-pressure networks in the last years. They put forward a number of formulas to be applied in hydraulic calculations of pipelines made from appropriate materials. However, nowadays

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both SP 32.13330.2012 [11] and other technical documents contain no strict unified procedures and recommendation for hydraulic calculation of gravity pipelines to be made from different materials. Application of different materials makes certain disorder both in theory and practice in calculating and designing non-pressure networks during repair thereof especially in the course of their no-dig repair, and thereby it requires the improved approach in unification and optimization of pipe calculation made from alternative materials [12-18].

The objective of the present work was to analyze the main approaches to the hydraulic calculation of straight sections of non-pressure pipelines and obtain the experimental hydraulic characteristics of two polymer pipelines used for trenchless renovation of gravity sewerage networks.

2. Theory of hydraulic calculations of gravity pipelines

The basis for hydraulic calculations is a condition for observance of uniform sewage water flow over the pipes under two basic formulae: flow continuity (1) and Chezy (2):

$$q = \omega \cdot V \tag{1}$$

$$V = C \cdot \sqrt{R \cdot i} \tag{2}$$

where q – fluid flow, m^3/s; ω – discharge area, m^2; V – mean velocity, m/s; R – hydraulic radius, m; i – hydraulic slope (to be equal to pitch of pipe under constant uniform flow); C – Chezy coefficient depending on hydraulic radius and roughness factor of pipeline wetted area, $m^{0,5}/s$.

Main problem in making hydraulic calculations is in finding Chezy coefficient C. A number of scientists proposed their own universal formulae (empirical and semi-empirical dependences) more or less describing dependence of Chezy coefficient C on hydraulic radius, roughness value of pipeline walls and other factors:

a) N.N. Pavlovsky formula [19]:

$$C = \frac{1}{n} \cdot R^{y} \tag{3}$$

where n – relative roughness of the pipe wall.

To determine y, formula is used:

$$y = 2,5\sqrt{n} - 0,13 - 0,75\sqrt{R}(\sqrt{n} - 0,1) \tag{4}$$

b) A. Manning formula [20]:

$$C = \frac{1}{n} \cdot R^{1/6} \tag{5}$$

c) To determine y, A.D. Altschtul and V.A. Ludov formula is used [19]:

$$y = 0,57 - 0,22 \lg C \tag{6}$$

d) A.A. Karpinsky formula [19]:

$$y = 0,29 - 0,0021C \tag{7}$$

Hydraulic calculation tables and nomograms enabling the mechanical engineers to make hydraulic calculations for non-pressure networks and conduits made from some materials are charted under the indicated and other similar dependences.

Non-pressure pipelines are recommended to calculate by [11] using Darcy-Weisbach formula [20]:

$$i = \frac{\lambda}{4R} \cdot \frac{v^2}{2g}, \tag{8}$$

where λ – pipe friction number; g – gravitational acceleration, m/s^2. Chezy coefficient C may be determined by formula (9) under combining formulae (2) and (8):

$$C = \sqrt{\frac{8g}{\lambda}} \tag{9}$$

A number of scientists note that in practice the calculations under the formulae indicated above and other formulae describing dependence of Chezy coefficient C on different values give 2 – 9% discrepancies in results [21] and even up to 20% [19] thereby indicating possibility in applying thereof in engineering calculations but with some errors. Such discrepancies are explained by the fact that each calculation formula to determine Chezy coefficient C has its own roughness factor, in particular formulae (3) and (4) – non-dimensional coefficient n.

Among above indicated formulae the formulae proposed by N.N. Pavlovsky (3) and Manning (5) are mostly approved and better agreed with the experimental results. These formulae are approved and tested in engineering practice and may be easily applied in hydraulic calculations of non-pressure network made of ceramics, concrete and bricks, i.e. for materials where roughness factor n is approximately 0.013-0.014. Recognizing formulae (3) and (5) one must admit that they do not consider fluid viscosity and therefore are active in quadratic area of hydraulic resistance only [19]. When applied in the transition area of hydraulic resistance where most of drain pipes are used, formulae (3) and (5) are to be adjusted due to lower roughness factors n that is typical for new generation polymeric pipes.

Obtaining of universal dependences for hydraulic calculation of pipes made from different polymer materials resulted in adjustment of roughness factors n, with Manning formula (5) being applied as the basic hydraulic dependence to determine Chezy coefficient to simplify the calculations.

3. Materials and methods

Two kinds of Wavin pipes were tested in the hydraulic test bench (Figure 1): corrugated polypropylene pipe DN 98 and bare pipe DN 105 made from unplasticized polyvinyl chloride.

The following procedure was used for making the experiment:

– reading of pressure values from piezometers and Pitot tubes in two points of fluid located at 10 m in wide range of pipeline pitch (0.001-0.03);

– metering of flow running by ultrasonic flow meter with further calculation of average values of hydraulic radius for different operations of pipeline with appropriate diameters and determining values of factors C and λ by plotting empirical dependences $C = f(R)$;

– application of obtained empirical dependences $C = f(R)$ and formula (5) to get relative roughness factor values n for pipeline appropriate material.

Fig. 1. Hydraulic test bench with non-pressure pipes to be tested (the first and second from the right).

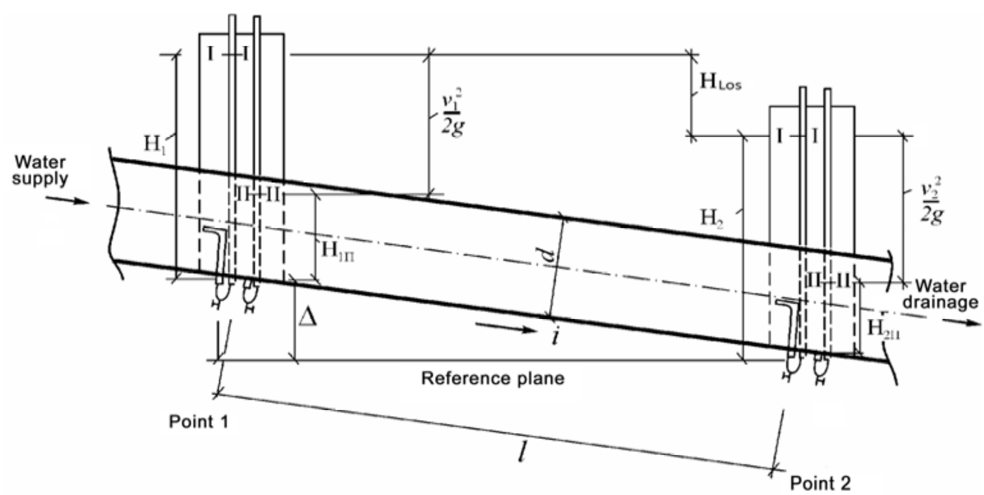

Fig. 2. Outline of hydraulic test bench.

4. Results and discussion

Full-scale experiment results to determine empirical dependences $C = f(R)$ are presented in Figure 3 and Figure 4.

Comparing the obtained dependences of $C = f(R)$ with formula (5) we calculated values of relative roughness n for three kinds of pipes under the calculated filling 0.6: $n_{1\ \text{pipe}}$ = 0.00998; $n_{2\ \text{pipe}}$ = 0.00939; if we compare the obtained values n with ceramic pipe relative roughness values $n_{\text{cer.}}$ = 0.0134, we may see the roughness of the pipes being tested to become significantly lower.

DOI: 10.1051/matecconf/201711209016

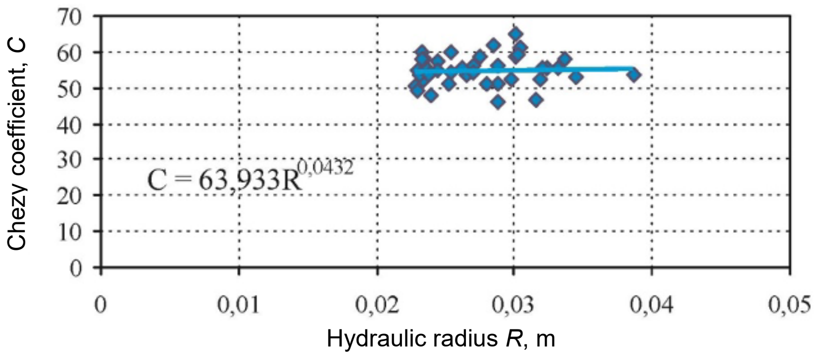

Fig. 3. Dependence curve of Chezy coefficient C on hydraulic radius R for the first pipe.

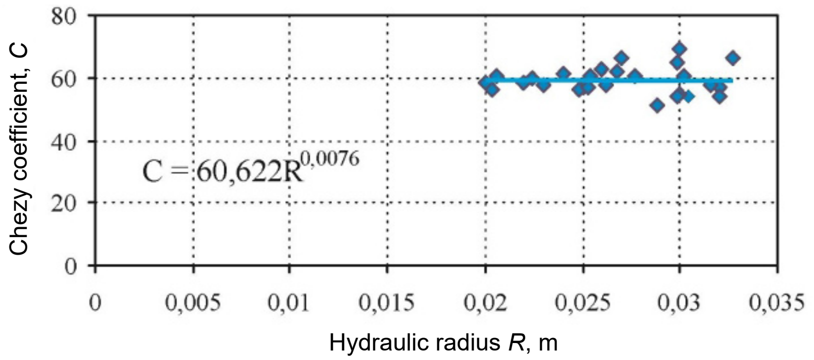

Fig. 4. Dependence curve of Chezy coefficient C on hydraulic radius R for the second pipe.

Therefore, experimentally found universal formulae (10 and 11) may be used by the design engineers to make hydraulic calculations to determine Chezy coefficient C under the calculated fillings. These formulae are adjusted to classical formulae of N.N. Pavlovsky (A. Manning) as:

$$C1\ pipe = 1/\ 0{,}00998R1/6 = 100{,}2R1/6 \tag{10}$$

$$C2\ pipe = 1/\ 0{,}00939R1/6 = 106{,}5R1/6 \tag{11}$$

5. Conclusions

1. The right choice of the repairing material enabling hydraulic compatibility between old and new pipeline sections made from different materials and of different diameters is the most important thing under no-dig restoration of worn pipelines.
2. Dependence of Chezy coefficient C on hydraulic radius, and calculated values of relative roughness factors for three kinds of polymer pipes that may be applied as the repairing material to be installed in available pipelines are obtained under hydraulic experiments in straight sections of pipelines.
3. High precision of calculating relative roughness factors n obtained for three functional dependences: linear, power and logarithmic is registered for all experiments in the appropriate flow range; these dependences may be applied as the calculated ones within the range of the tested filling h/d (similar to the calculated) and as hydraulic radii R.

4. Absolute values *n* calculated by Pavlovsky and Manning formula differ slightly (from 4 to 14% at the average). Such discrepancies may be considered as accepted for the engineering calculations because A. Manning and N.N. Pavlovsky formulae may be actually interchanged in further hydraulic calculations of non-pressure pipelines.

5. Negative aspects due to flooding of some sections of the network and surging of pressure head (water level) are experimentally found on curved pipelines in wide slope range (0.01-0.03). Under the results of analyses made it may be basically concluded that experimental developments confirm the intertubular space is to be filled to exclude any pipeline irregularities due to temperature differences and stabilization of hydraulic values.

6. The results of the research will be useful for choosing an optimal new pipe materials when considering the problems of ensuring the hydraulic compatibility of old and new sections of the drainage network that are renovated by polymer pipes.

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