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Issue of annular space filling requirement in engineering networks renovation justification

R Hurgin and M Chudakov

Moscow State University of Civil Engineering, 26, Yaroslavskoe Highway, Moscow, 129337, Russia

E-mail: hurgin@mgsu.ru

Abstract. The main research aim was to determine the feasibility of filling the annular space with cement or other mortar during the renovation of dilapidated drainage networks with one of the common trenchless methods, i.e. by pulling pipes of smaller diameter through them (stalks from a roll). If polymer pipes are used for pulling, justification for the use of filling is necessary, due to their specific properties, which can affect the pipeline system strength and hydraulic performance. The article discusses the need for the pipelines annular space cementation during trenchless repairs.

1. Introduction

The polymer pipes elongate when ambient temperature or the transported liquid temperature increases. In this case, the parameter of material thermal (linear) expansion is characterized by the linear expansion coefficient of the material and does not depend on the pipe diameter [1].

When pulling stalks of polyethylene pipes, for example, first of all, one should consider eliminating a negative reaction in a concentrated point load, i.e. the pipeline support on a rigid object (pipe wall) anywhere along its length, which over time may lead to the fractures appearance and propagation. In addition, it is necessary to assess the change in the pressureless pipelines hydraulic characteristics as a means of ensuring efficient wastewater transportation when a pipeline deflection is possible due to its elongation in the absence of filling. This circumstance plays a significant role in ensuring the hydraulic flow indicators required by the project. This is why filling is important.

The above problems were solved using theoretical calculations and the field tests' results on polyethylene pipelines in the MGSU water supply department laboratory.

2. Materials and methods

Task matter. A 150 mm diameter cast iron pipeline trenchless repair is carried out by pulling a *95 mm* internal and *110 mm* external diameter polyethylene pipeline through it. The pipeline length (well to well) $S = 40$ m. The transported wastewater daily temperature variation $\Delta t = 40 - 20 = 20°C$. The polyethylene linear expansion coefficient $K = 0{,}00022$ m/°C.

To be defined:

-the pipeline linear extension value ΔS, m;

-possible elongated polyethylene pipeline configuration when it is located in an old pipeline with specified pipe diameters;

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- possible deformed polymer pipeline basic geometric parameters, i.e. the number and length of bends (waves), deflection height above the tray, etc.;
- the pipeline lengthening consequences in terms of changes in hydraulic elements and the impact on the pipeline system strength characteristics;
- the possibility of eliminating or minimizing the consequences associated with the pipeline linear expansion.

3. Results and discussion

The *40 m* polyethylene pipe stretched inside the old pipeline linear elongation value is determined by the following equation (1):

$$\Delta S = \kappa \Delta t S = 0,00022 \cdot 20 \cdot 40 = 0,176 м \tag{1}$$

Thus, the new length of the polyethylene pipe considering the thermal elongation will be $P = S + \Delta S = 40.176$ *m.*

As we assume the pipeline extension to be uniform, the P value is expressed as the arc length, the initial pipeline length as the chord $L = AB$, and the chord $l = AM$, which is shown schematically in Figure 1.

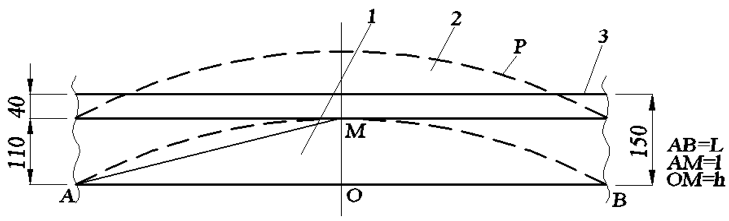

Figure 1. Schematic position of polyethylene pipe initial position and virtual deflection (bending) in the pipeline being repaired: 1 - initial position of the polyethylene pipeline; 2 - configuration of the polyethylene pipeline virtual position deflected after extension; 3 - repaired pipeline

In order to define the maximum deflection or ridge $h = OM$ (see Fig. 1), we use the Huygens equation (2) for the arc length [2]:

$$P = 2l + \frac{1}{3}(2l - L) \tag{2}$$

Since the P value is known, we transform equation (2) into equation (3) to find the chord length l:

$$l = \frac{3P + L}{8} \tag{3}$$

Substituting the values of the known variables in the equation (3), we determine the chord length $l = AM = 20.066$ m. Next, from the right triangle *AMO* we determine the deflection height $h = OM$ using the Pythagorean equation (4):

$$h = OM = \sqrt{AM^2 - AO^2} = \sqrt{20,066^2 - 20^2} = 1,626 м \tag{4}$$

The deflection $h = 1.626$ *m* is virtual, since it goes beyond the old pipeline dimensions. The maximum allowable deflection under the two-pipe construction conditions can be only $h = 150 - 110$ *mm* or *0.04 m*. In this case, the real configuration of the polyethylene pipeline will be different, namely with a “snake” shape bend with a large number of waves (deflections), as schematically shown in Figure 2.

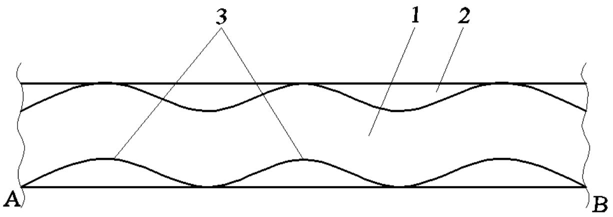

Figure 2. Approximate configuration of the polyethylene pipe real condition inside the restored pipeline: 1- Deflected polymer pipeline after elongation; 2- restored pipeline; 3- deflections ridges (waves)

In order to describe the new polyethylene pipeline configuration, we use the Huygens equation (2) and determine the geometric parameters of "distortion", i.e. the actual number of deflections (waves) and their heights. Developing the hypothesis that the deflections are evenly distributed, and that the assumed deflection height will be uniform along the pipeline length and not exceed *0.04 m*, the number of waves can be *1.666 / 0.04 = 40.65* pieces. Then, conditionally accepting the design sections number in the form of uniform elementary arc lengths along the entire well to well pipeline length in the amount of *40* pcs; the length of one deformed section will be *40 m/41 = 0.976 m.*

To test the hypothesis, we consider one elementary deformed section to be *0.976 m* long (see Fig. 1). From the right triangle *AMO*, the chord length $l = AM$ is determined by the following equation (5):

$$l = AM = \sqrt{OM^2 + AO^2} = \sqrt{0,04^2 + 0,488^2} = 0,4896\text{м} \quad (5)$$

To find the arc length P using the Huygens equation (2):

$$P = 2l + \frac{1}{3}(2l - L) = 2 \cdot 0,4896 + \frac{(2 \cdot 0,4896 - 0,976)}{3} = 0,980266\text{м}$$

Thus, the arc length is *0.980266 m*, which is greater than the section (chords) length in the initial state, i.e. *0.976 m*. The difference between these values corresponds to elongation and is *0.004266 m*. The calculated elongation according to equation (1) is:

$$\Delta S = \kappa \Delta t S = 0,00022 \cdot 20 \cdot 0,976 = 0,00429\text{м}$$

Thus, the difference between the design *0.00429* and the estimated *0.00466* values is negligible and is less than *0.56%.* This proves that the number of deflections (waves) after the polyethylene pipeline thermal elongation will be about *40* pcs.

According to the results interpretation, the following should be noted: the polyethylene pipeline used for renovation, undergoing linear extension, acquires the "snake" configuration, which affects the two-pipe system strength characteristics, since there is a risk of negative supports in about *40* pressure points, which can provoke stresses leading to the polymer pipeline defects appearance, as well as to increased stresses on the old pipeline wall. Hence, the main conclusion from theoretical assumptions is the need for filling the annular space, preventing the polymer pipeline deflection within the dimensions of the old one.

In order to prove the need for filling from the hydraulic flow indicators preserving point of view, a series of field experiments were conducted on deformed pipelines simulating the thermal elongation effect.

The experiments were carried out on a hydraulic stand; a general layout is shown in Figure 3.

The experiments were carried out according to a specially developed technique, including several hydraulic indicators determination using piezometers and pitot tubes installed respectively at points 1 and 2 near the 10 m pipeline beginning and end. Hydraulic experiments were carried out with two pipeline configurations: with one and with two waves and different sizes of ridges.

Figure 3. Hydraulic stand with a deflected pipeline of two-wave configuration

The studies were carried out with a wide range of pipeline slopes (0.01-0.03) both with a constant and variable flow rate (speed) measured with an ultrasonic flow meter.

The experiments aim on the pipeline curved sections was to show a picture of the fluid flow hydraulic elements changes and evaluate their consequences for the non-pressure sewage networks effective operation, primarily, as a reason for their transporting ability violation. The latter circumstance is very significant for ensuring the required hydraulic indicators of small diameter drainage networks, in particular of drainage outlets from buildings and the yard network.

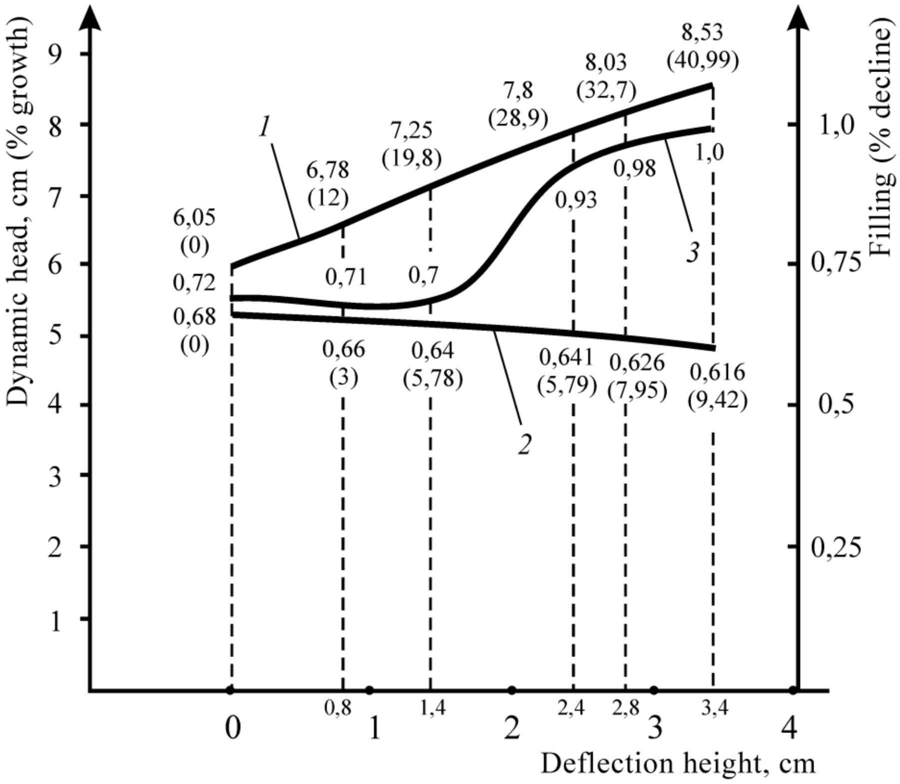

Figure 4. Influence of deflection height on dynamic head and filling: 1, 2 - the dynamic head growth rate and the filling decline, respectively (in absolute terms and in percent), 3 - backwater curve (filling increase) before the point 1 (at the beginning of the deflection)

During the operation of the pipeline with one deflection (wave), the analysis was made to identify change patterns in the dynamic head and filling from the size of the ridge up- and downstream the deformation section with ramps of 0.01 or above and a constant flow rate. The changes dynamics were assessed in the absolute values of these variables, as well as their growth or decline percentage in the settlement area between points 1 and 2. The experimental results are presented in the graphs of Figure 4.

As follows from the Figure 4 graphs (curve 1), a significant increase in the dynamics head is observed: from 12 to 40, 99% in the ridge values range 0.8 - 3.4 cm. This, above all, indicates the local flow rate increase after overcoming the obstacle, for example, in 1.18 times with a 3.4 cm ridge. However, filling decreases after an obstacle. Moreover, according to the decline curve 2, the dynamics are as follows: from 3 to 9.42%. In addition, the ridge presence leads to backwater upstream of it (curve 3). It is formed at a certain ridge height (in experiments with a 0.01 ramp at values from 1.4 to 2.4 cm). In addition, a decrease in the pipeline filling downstream the ridge can adversely affect the transportation of bulk impurities i.e. does not foster their uniform movement within the fluid flow.

The experiments with two pipeline ridges confirmed the negative changes dynamics in the hydraulic flow elements at all pipeline operation modes in the ramp range of 0.01-0.03. The change dynamics (increase) in the dynamics head from the ridges height is presented in Table 1.

Table 1. Hydraulic test results at a constant flow rate, various slopes and ridge heights

Pipeline ramp, i	Ridge height, cm	Dynamic head, point 1, cm	Dynamic head, point 2, cm	Dynamic head increase, times
0.01	1.5	5.2	7.80	1.50
	3.0	2.8	9.70	3.46
0.015	3.0	5.9	10.4	1.76
	4.5	1.8	12.5	6.94
0.02	4.5	6.5	13.2	2.03
	5.5	4.5	14.0	3.11
	6.5	2.2	15.8	7.18
0.025	6.5	7.3	16.8	2.31
	7.5	7.3	17.8	2.43
	8.5	2.9	19.1	6.58
0.03	8.5	6.4	19.8	3.40

According to the data in Table 1, a strict trend is observed: an increase in the i ramp with a constant ridge height, for example, for 4.5 cm with i = 0.015 and i = 0.02 or 6.5 cm with i = 0.02 and i = 0.025 etc. leads to a smaller increase in dynamic head. A similar pattern was observed with consumption increase and constant ramp. For example, according to experiments on two waves with a slope of i = 0.03 and a crest height of 8.5 cm, the drop in the dynamic head is 3.4 times at 15.27 m^3/h flow rate, 3.05 times at 17.02 m^3/h flow rate and 2.79 times at 21.2 m^3/h flow rate. In other words, ramp or flow rate increase is a way of compensating for the pipeline curvature. Thus, we can conclude that the worst conditions for wastewater transporting will obviously be observed with small ramps and pipeline network diameters during minimal water consumption periods.

Thus, in the presence of several waves and, accordingly, ridges of various heights, the flow pattern becomes chaotic: the velocity pulsates, local regions working at full filling are observed, and the overall filling decreases. This can lead to the obstructions or sediments formation during transportation of real wastewater stream containing bulky impurities and sand.

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4. Conclusion

The main conclusion based on the research results is that theoretical and experimental developments confirm the need for annular space filling, which will eliminate the pipeline waviness due to temperature variations and thereby prevent negative effect on the hydraulics and structural strength.

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