Computer simulation study of the vacuum effect during sewage pipelines annular space backfill in trenchless renovation

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Abstract. The article presents material that may be useful for designers and researchers involved in the pipeline material selection for the water supply and sanitary sewer networks construction and reconstruction. During renovation of a dilapidated pipeline by pulling a new polymer pipeline into it, the annular space is filled with cement mortar. The influence of vacuum effect on the strength characteristics of the pipeline when it is filled with cement mortar is considered. The influence of groundwater on the pipeline stability and vacuum in the annular space is presented.

1. Introduction

The purpose of computer modeling and the subsequent results interpretation was to analyze the polymer pipeline strength parameters changes dynamics in the presence of vacuum, depending on the type and specific gravity of mortars used to backfill [1], the presence and magnitude of groundwater pressure over a two-layer pipeline system of a certain diameter and SDR value (diameter to wall thickness ratio), backfill method (uniform or irregular).

Over the past 20 years, due to the need to restore pipeline systems in cities and towns both in our country and abroad, trenchless pipe laying methods have become widespread [2]. Among these methods is the technology of dragging new pipes into worn pipelines. Basically, polyethylene, polypropylene and fiberglass pipes are used for restoration of the worn-out pipelines. These pipes have high corrosion resistance, but are inferior to steel and cast iron pipes in stiffness. If polymer pipes are laid without taking into account this specificity, then they are deformed and fail during operation, sometimes already at startup. Pipes are deformed under pressure from soil and passing vehicles, but also if cemented in a casing or an old pipeline.

The mortars of various consistencies used in computer modeling acted as strength enhancers of two-layer pipe structures [3]. In addition, the presence of cement mixtures in the annular space almost guaranteed the prevention of negative consequences associated with polyethylene pipes linear elongations with the change of the transported medium or ambient temperature. The type of mortar used in the annular space is not specified.

The annular space filling with mortar is performed as follows. Special shields are installed on both sides of the pipeline, a hole is made in the shield, and the solution is pumped into the annular space. In this case, special activities for the air removal from the cavities formed in the pipeline soffit are not prescribed. More attention is paid to fill the pipe bottom with the mortar. Since the mortar is pumped under pressure, the vacuum formation in the annular space and, as a result, its influence on the pipeline bearing capacity in presence of groundwater is possible.

2. Materials and methods

In order to understand how vacuum pressure acts on a three-layer structure in combination with other loads, we simulated situations in different conditions and with different loads applied on the studied structure using the Pipes 11 software.

The calculations without taking into account the vacuum effect on the structure and calculations taking into account the vacuum effect are presented below.

During the modeling period, cement mortars with the corresponding specific gravities: with gravel or crushed stone (25,000 N/m^3), sand (20,000 N/m^3) and slag (15,000 N/m^3) fillings were considered as building mixtures used for packing.

Computer simulation consisted of the mortars counteracting loads determination, which are perceived by a low-pressure polymer pipe (HDPE) with various annular space filling options (uniform or irregular), as well as the filler absence or presence in the polymer pipeline, which is usually water. One of the main calculations criteria is the condition of round pipe cross section ovalization degree (elongation) staying within the range of 5% of diameter. To reveal the mortar loads impact pattern on the polymer pipeline and the groundwater ascent resistance, the source information was used to add wide range of groundwater pressure with a 0.1 MPa increment when the restored pipeline is laid at a depth of 10 m from the surface.

The following is a pipeline system automated mode calculation example after restoration of a cast-iron pipeline with an inner diameter D = 0.8 m by a polymer pipe with diameters d_o = 0.63 m and d_i = 0.52 m, where the information presented in the dialog box is used as the initial data (see Figure 1).

The results of automated calculations and their interpretation are given below.

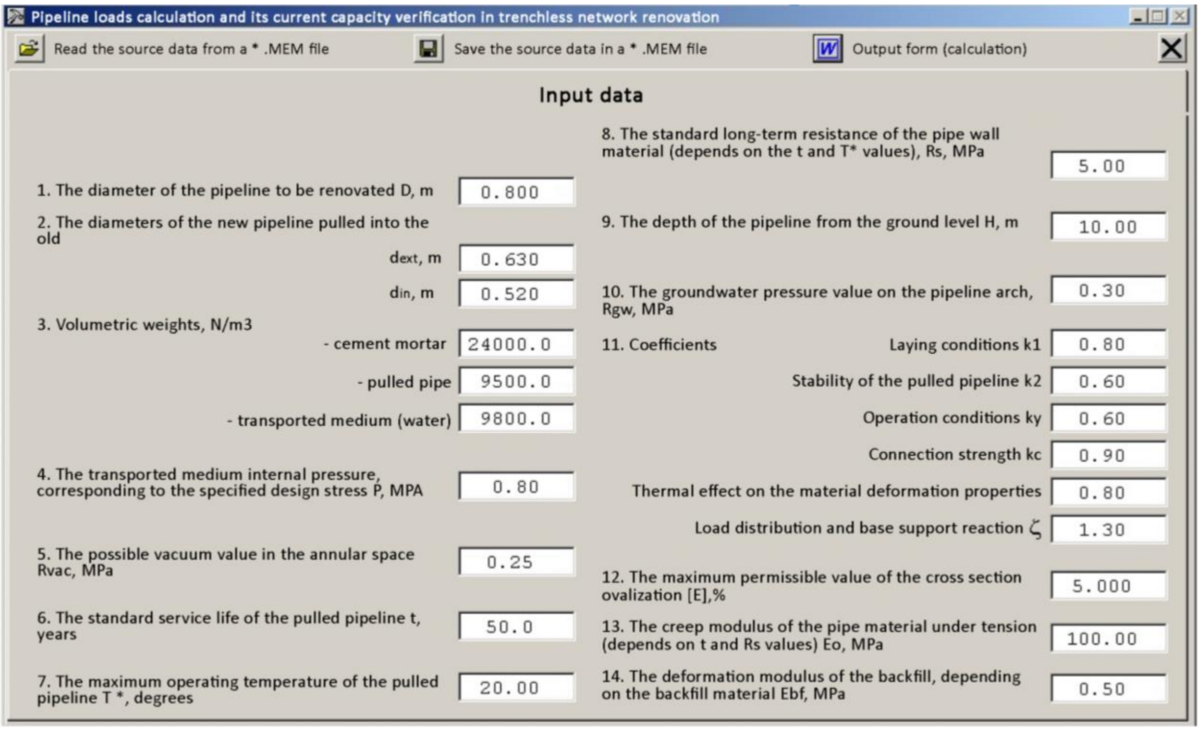

Figure 2. Pipes 11 software dialog window

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3. Results and discussion

3.1. Vacuum pressure on the pipeline is not taken into account

Regarding the pipeline diameter deformation (i.e., the degree of ovalization of the polymer module), it is necessary to state the following: for the annular space filling considered cases, the ovalization degree did not exceed the maximum permissible value, namely 0.1579%: in the scheme A load case, then 0.0775% in scheme B, (i.e., less than 5%). As for cases C and D, when the annular filling is irregular, there were the following results according to the ovalization degree: with load according to scheme C 0.1801%; the same with scheme D 0.1618%.

Thus, we may state that the filled polyethylene modules have positive effect on the annular space filling. The filler (water) counteracts deformations and at the same time prevents the polymer pipeline from floating up when the mortar is injected. The following figures indicate a decrease in the ovalization degree compared to an empty pipeline: ovalization will decrease by 0.1579/0.0775 = 2.04 times. A similar outcome, but to a lesser extent, is observed with the annular space irregular filling: ovalization decreases by 0.1801/0.1618 = 1.11 times.

Figure 2 shows, as a sample, the radial pressure change diagrams for four pipeline system operation characteristic cases with backfill of A, B, C and D.

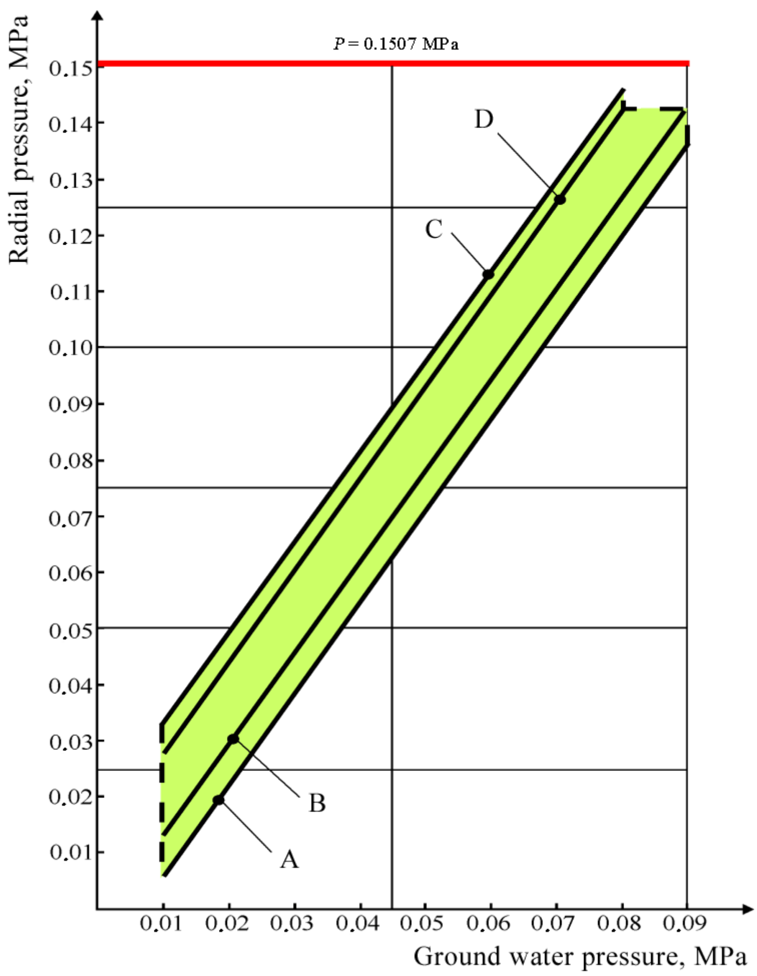

Figure 2. Radial pressure versus ground water pressure for four pipeline operation cases

3.2. Vacuum pressure is taken into account

When checking the pipeline bearing capacity according to condition III, when pulling the pipeline with SDR11, the following can be specified: the circular stability of the pipeline is ensured in all four cases only if the groundwater pressure is in the range from 0.1 to 0.25 and vacuum pressure is 0.1. If the vacuum pressure is 0.2, round stability in all four cases is ensured if the groundwater pressure is up to 0.2.

If vacuum pressure is 0.3, stability is not ensured even in the absence of groundwater pressure on the pipeline.

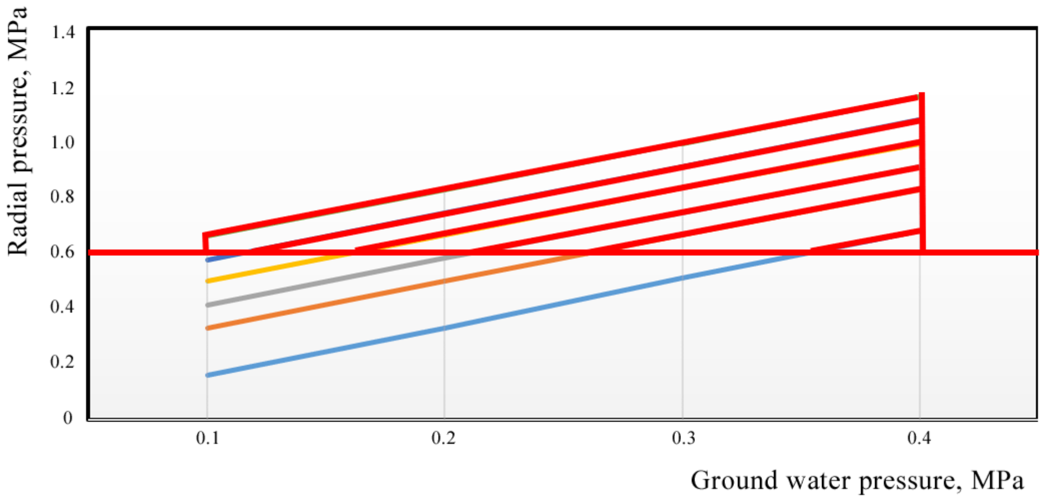

Figure 3. Graphic representation of vacuum pressure and groundwater pressure values correlation for a pipeline at SDR 11

Table 1. Vacuum pressure values in the annulus at different groundwater pressure values at SDR11

$P_{ground\ water}$	$P_{vac\ 0.00}$	$P_{vac\ 0.1}$	$P_{vac\ 0.15}$	$P_{vac\ 0.2}$	$P_{vac\ 0.25}$	$P_{vac\ 0.3}$
0.1	0.1613	0.3280	0.4113	0.4946	0.5710	0.6544
0.2	0.3280	0.4946	0.5780	0.6613	0.7377	0.8210
0.3	0.5082	0.6613	0.7377	0.8280	0.9044	0.9877
0.4	0.6748	0.8210	0.9044	0.9877	1.0710	1.1544

4. Conclusion

When cementing the space between the pipes' walls and the casing, it is necessary to take into account the solution gravitational effect on the pipeline.

In order to prevent pipe deformation under solution hydrostatic pressure, it is necessary to install the intermediate supports on the cased pipeline or to carry out cementation in several steps.

When cementing the annular space it is necessary to use solutions with plasticizers.

When calculating the loads on the pipeline and checking its bearing capacity, it is necessary to take into account additional loads from vacuum pressure

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