Improvement of the technology for laying corrugated pipes for creating culverts under roads

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Abstract. The widespread use of polypropylene corrugated pipes for free-flow culverts requires that the construction technology ensure compliance with their physical and mechanical characteristics during their service. The use of polypropylene corrugated pipes for culverts in road construction poses greater demands on them. The paper considers the behavior of a buried pipe in interaction with the surrounding soil. The contradictions in the current building codes and regulations have been revealed. It has been proven that for polypropylene corrugated pipes, the resistance of the backfill soil, depending on the degree of compaction, is an essential factor in ensuring the long-term stability of the circular cross-section of the pipe. Theoretical calculations have confirmed that, depending on the backfill depth, the relative deformation of polypropylene corrugated pipes may exceed the maximum permissible values. An engineering solution has been proposed that provides an increase in the rigidity of the pipe bearing reaction under compressive forces and a decrease in the load from vehicles.

1. Introduction

Today, polypropylene corrugated pipes have almost everywhere come to replace pipes made of other materials (concrete, asbestos cement, metal, etc.) to create free-flow engineering systems. First of all, they are used in the newly constructed storm and waste sewers. However, the scope of their use is constantly expanding. Depending on their physical and technical characteristics and geometric parameters, corrugated pipes are systematically used to create culverts under roads, electrical channels for laying cables, ventilation systems and other engineering structures.

Initially, pipes from foreign companies (Pragma, Ecopal, DKS, etc.) were used on the Russian market. Later, due to high demand, European technologies were purchased and on their basis Russian production facilities were created (Korsis, Ikaplast, Politron, etc.), whose products are of comparable quality.

The widespread use of corrugated polypropylene pipes is explained by a number of their advantages: durability (estimated service life is at least 50 years); resistance to impacts from transported resources (corrosion, chemical, temperature); preservation of tightness during possible movements of the soil (deformation capacity due to the properties of flexibility).

An important indicator of drainage and sewerage networks is their resistance to wear from solid particles contained in the transported liquid. In accordance with the so-called Darmstadt Procedure...
Polypropylene is the least susceptible to abrasive wear [1]. The results were obtained based on studies, the technique of which is that 1-meter long pipe sections (samples) are filled with an aqueous suspension with various additives of abrasive particles. Further, these samples on a special stand swing with a certain frequency. As a result of the movement of particles, real wear is simulated in an active pipeline. After a certain number of oscillations have elapsed, the change in the wall thickness of the samples is registered.

This assessment is carried out by Süddeutsche Kunststoffzentrum and other well-known companies (Borealis, Uponor, Wavin, et al.).

It has been experimentally proved that for polypropylene pipes such wear will not exceed 0.5 mm over the entire operating period (Fig. 1).

**Figure 1.** Abrasion curve of various pipe materials according to the Darmstadt procedure: 1 - concrete pipe; 2 - concrete pipe coated; 3 - GFK pipe; 4 - clay pipe; 5 - PVC pipe; 6 – PP pipe

The manufacturers claim that the use of polypropylene corrugated pipes is economically feasible, because not only their cost is lower in comparison with pipes made of other materials, but also there is lower costs of transportation, installation and maintenance.

However, the use of polypropylene corrugated pipes for culverts in road construction poses greater demands on them. In particular, water currents carrying significant amounts of sand, gravel, or stones can deform the material at a much greater rate than the results shown in Figure 1.

Also, the small wall thickness and, as a consequence, the relatively low ring stiffness of corrugated pipes (in comparison with concrete, metal, and even polyethylene) makes it necessary to strictly adhere to the requirements for laying technology.

2. **Current situation and formulation of the problem**

Culverts with corrugated polypropylene pipes are the most important structural elements of roads. The general condition of the road, ensuring the safety of traffic on it and protecting the environment, depends on their operation.

Currently, pipes of various types are used in the construction of highways of all categories. Polyethylene pipes are increasingly being laid by trenchless methods [2]. However, due to possible deformation when using known means of trenchless laying, the so-called cut-and-cover method continues to be used for polypropylene corrugated pipes, involving the creation of a trench.
After laying the pipe in a trench, the most stringent requirements are imposed on the process of compaction of the soil body surrounding the pipe (soil cage). This process must be carried out in such a way that the pipe laid under the road either does not deform at all, or returns to its original position after the load from the vehicle. Such a return is possible due to elasticity and resilience of the pipe (Fig. 2).

**Figure 2.** Diagram of deformation changes in a corrugated pipe: (a) deformation from loading from the side of the vehicle; (b) restoration of the shape upon termination of the load

The structural characteristics of a flexible pipe during its burial have been studied for a long time [3]. In a number of countries, the limiting state of the possibility of normal operation is established by comparing vertical deformations from loads with permissible deformations. As a rule, a series of experimental studies are carried out for this purpose (Fig. 3).

**Figure 3.** General view of laboratory test facility

As a result of such studies, the local maximum possible bending is assessed depending on the profile and thickness of the pipe wall [4, 5].

However, the real behavior of the buried pipe should be considered together with the surrounding soil cage, since they form a single structure that takes the loads acting on the structure [6, 7].

Thus, the rebound from the backfilled soil is an indicator that determines the behavior of the pipe (in conjunction with its own strength performance). Insufficient soil compaction can lead to lateral buckling and loss of pipe stability due to unacceptable deformations.

It is necessary to determine whether the standardized value of the degree of compaction ensures guaranteed preservation of the strength performance of the corrugated pipe material.
3. Analysis of reference documents and calculation methods

The organization of construction operations for the laying of water supply and sewerage networks is carried out in accordance with the regulated requirements.

The reference document of the Russian Federation on soil compaction around the pipe stipulates the following requirements: “When backfilling pipelines, a protective layer of sandy or soft local soil with a thickness of at least 30 cm, not containing solid inclusions (crushed stone, stones, bricks, etc.), must be installed above the top of the pipe. Tamping the pipeline with soil is carried out with a non-mechanized hand tools. Compaction of the soil in the cavities between the trench wall and the pipe, as well as the entire protective layer, must be carried out by manual mechanical ramming until the compaction coefficient established by the project is achieved. Compaction of the first protective layer with a thickness of 10 cm directly above the pipeline is carried out with hand tools”.

For clarity, these requirements are shown in Figure 4.

![Figure 4. Soil compaction scheme when backfilling trenches: 1, 4 - layers of soil compacted with hand tools; 2, 3, 5 - layers of soil compacted with mechanized hand tools](image)

From the information presented in the diagram, it follows that the labor intensity of earthworks is extremely high. According to the preliminary calculations, all the savings associated with the installation of a corrugated pipeline (versus, for example, a metal one) will be lost (and even exceeded) as a result of labor costs during layer-by-layer filling and compaction using manual labor (Fig. 5).

![Figure 5. General view of a soil cage compaction](image)

In addition, the outlined technology of soil compaction around a corrugated pipe conflicts with the requirements set out in the road construction codes and regulations, in accordance with which, the minimum coefficient of soil compaction in the working layer of the excavation (up to 6 meters) should not be lower than 0.95 (Table 1).
Table 1. Degree of Soil Compaction

| Layer depth from the road surface (m) | Compaction coefficient under the capital road surface depending on the natural and climatic zone (I - V) |
|--------------------------------------|--------------------------------------------------------------------------------------------------|
|                                      | I                                                                                   | II, III                              | IV, V                                                                 |
| < 1.5                                | 0.98-0.96                                                                          | 1.0-0.98                             | 0.98-0.96                                                           |
| 1.5-6.0                              | 0.95                                                                                 | 0.96-0.95                            | 0.95                                                                 |

The required compaction cannot be achieved using hand tools or mechanized hand tools even if the optimum moisture is maintained. Given the cramped conditions of the operations, it can be assumed that with a high probability the zones located directly under the pipe will remain not only non-compacted, but also not filled with sufficient quality.

Previous experience [8] was used in carrying out the necessary assessment of pipe deformations and a program of static calculations has been developed.

The serviceability of an underground pipeline (bearing capacity) can be determined by the condition of the maximum permissible value of the relative deformation of the pipe cross-section (shortening of the vertical diameter):

\[
\frac{f}{D} \cdot 100\% \leq [\varepsilon],
\]

where \( f \) - vertical deformation of the corrugated pipe (mm); \( D \) – nominal diameter (mm); \([\varepsilon]\) - maximum permissible relative deformation (%).

The soil cage should be considered as an elastoplastic medium, while it is necessary to assess the zones of maximum equilibrium in the body of the soil cage.

With an increase in deformation, the horizontal component of the soil pressure increases, gradually passing from a passive form to an active form. As a linearly deformable body, the soil cage resists the pipe pressure. Then, in accordance with the classic expression of Spengler, the deformation depends on the vertical load, the stiffness of the soil and the stiffness of the pipe itself:

\[
\varepsilon = \frac{c_1 q}{c_2 SN + c_3 E_S},
\]

where \( q \) – intensity of vertical soil load (MPa); \( SN \) – ring stiffness of the pipe (MPa); \( E_S \) – secant soil modulus (MPa); \( C1 \) – coefficient of influence on the deformation of the intensity of the vertical load of the soil; \( C2 \) – coefficient of influence on deformation of pipe ring stiffness; \( C3 \) – coefficient of influence on the deformation of the secant soil modulus.

Distributed vertical load consists of two components:

\[
q = q_1 + q_2.
\]

Where \( q_1 \) – distributed load from vehicle; \( q_2 \) – distributed load from soil above the pipe.

The load from the vehicle side (according to the Boussinesq pressure distribution theory) depends on the pipe laying depth:

\[
q_2 = 0.478 \cdot \frac{T}{H^2},
\]

where: \( T \) – vehicle axle load (kN); \( H \) – pipe backfill depth (m).

The density of the soil above the pipe (to determine \( q_1 \)) when compacted with power tools will not exceed 19 kN/m³.

The standard ring stiffness for polypropylene corrugated pipes corresponding to the stiffness class SN 8 is 8 kN/m² (0.008 MPa).

The degree of compaction and the type of soil determine its secant modulus (ES). When compacting with power tools, its value cannot exceed 3.0 MPa.

The coefficients of influence on deformation (\( C1, C2, C3 \)) are established by reference documents.
4. Results and Discussion

In accordance with the stated dependencies (1-4), statistical calculations have been performed. The secant modulus was set to the maximum possible for compacting the soil cage with power tool (ES = 3.0 MPa). The calculations have been carried out taking into account the movement of heavy land transport (T = 260 kN).

Table 2 shows, by the example, the results obtained for PP corrugated pipe “DN/ID 800 mm SN8”.

| Backfill depth (m) | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 |
|-------------------|-----|-----|-----|-----|-----|-----|-----|
| Relative deformation (%) | 8.7 | 6.3 | 5.2 | 5.2 | 5.8 | 5.9 | 6.3 |

The limiting relative deformations set by the manufacturers should not exceed 6%. Consequently, it turns out that the technology of laying polypropylene corrugated pipes described in the normative documents ensures the safety of their physical and mechanical characteristics only at depths ranging from 2.0 to 3.5 meters.

To address this contradiction, it is proposed to improve the technology of creating a soil cage around the pipe (Fig. 6).

The construction of additional membranes in a soil cage may be proposed as reinforcing elements. To create membranes, various non-woven and synthetic materials or a primer together with various binders can be used as structural and supporting materials. For example, it is proposed to make membranes from a geocell filled with sand-gravel or crushed stone, wrapped in geotextile.

The main task of the horizontal stops (1) is to increase the resistance to vertical loads acting on the pipe and to reduce its relative deformations. The damping layer (2) will allow the use of generally accepted mechanized technical means of compaction of the overlying soil. Both layers (1 and 2) will prevent possible settlement in the underlying soil mass, which is possible over time due to insufficient compaction.

5. Conclusion

The requirements for the technology of soil compaction around the corrugated pipe set out in the reference documents are in conflict with the requirements set out in the norms and rules for road construction.
It has been proven that for polypropylene corrugated pipes, the resistance of the backfill soil, depending on the degree of compaction, is an essential factor in ensuring the long-term stability of the circular cross-section of the pipe.

Theoretical calculations have confirmed that, depending on the backfill depth, the relative deformation of polypropylene corrugated pipes may exceed the maximum permissible values.

An engineering solution is proposed, which consists in the construction of additional membranes in a soil cage.

It is necessary to adjust building codes and regulations. These amendments should require the creation of additional reinforcing layers that provide an increase in the rigidity of the pipe resistance during deformation and a decrease in the load from the sealing means when creating a road and from vehicles during its operation.

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