BG Pulse Journal USA
ISSN:1947-2536 http://www.bgpulseusa.com/index.php/bg
BG PULSE JOURNAL

EXPERIMENTAL STUDY OF THE STRESS–STRAIN STATE OF UNDERGROUND RIGID PLASTIC PIPES UNDER TRENCH CONDITIONS

Abdimominov Erkin.
Karshi State Technical University
Professor, Department of General Technical Sciences
Sharipov Shuxrat Po'latovich
Karshi State Technical University
Associate Professor, Department of General Technical Sciences
Radjabov Mansur Rustamovich
Karshi State Technical University
Associate Professor, Department of General Technical Sciences
mradjabov937@gmail.com
ORCID 0009-0003-0774-7766
https://doi.org/10.5281/zenodo.20339903

Abstract. Polymer pipes buried underground are widely used in many engineering sectors. However, accurately assessing the stress–strain processes that occur in the pipe wall under trench conditions still remains a complex problem. In this article, HDPE pipes with a diameter of 200 mm were investigated in laboratory conditions based on a trench model. The burial depth was 1.2 m, and the soil had a mixed composition. The variation of radial displacement and ovalization parameters depending on loading was studied. The results showed that the deformation has a nonlinear character and that burial conditions significantly affect the ring stiffness. The obtained data can be used for calibrating numerical models and improving design standards.
Keywords: HDPE, trench, deformation, radial displacement, ovalization, soil–pipe interaction.

INTRODUCTION.

In recent decades, polyethylene (HDPE) pipes have become one of the main materials widely used in water supply, sewerage, gas distribution, and industrial infrastructure systems. Their light weight, resistance to corrosion, ease of jointing, and low operating costs increase the economic efficiency of such systems [1, pp. 14–16]. At the same time, the strength of pipes operating underground depends not only on the material properties, but also on the mechanical state of the soil, trench geometry, degree of compaction, and the nature of external loads [2, p. 32].

Practical experience shows that pipelines often operate under the influence of uneven settlement, dynamic loads, changes in soil density, and stress concentrations at joint locations. As a result, radial displacement, ovalization, and time-dependent deformations occur in the pipe wall [3, pp. 58–60]. In polymer pipes, in particular, the stress–strain process becomes nonlinear due to elastic–plastic and viscoelastic behavior [4, p. 21].

In the scientific literature, various theoretical models have been proposed to describe soil–pipe interaction — including elastic foundation models, ring-stiffness equations, half-space approaches, and numerical methods (FEM) [2, pp. 40–45]. However, since these models rely on numerous assumptions, it is necessary to verify and calibrate them using experimental data [1, p. 73]. For this

reason, full-scale or laboratory trench tests are of great importance: they make it possible to evaluate how closely theoretical calculations correspond to real operating conditions [5, pp. 96–98].

In addition, although the literature more frequently presents data on large-diameter and thick-walled pipes, the deformation mechanisms of HDPE pipes with diameters of about 200 mm under trench conditions have not been sufficiently addressed [3, p. 63]. From this point of view, the present study is aimed at investigating the stress–strain state of buried HDPE pipes on the basis of laboratory experiments, with particular emphasis on analyzing the load-dependent variation of radial displacement and ovalization.

2. MATERIALS AND METHODS

High-density polyethylene (HDPE) pipes were selected as the research object. The relatively low density, high flexibility, and chemical stability of HDPE make it widely applicable in underground pipeline networks [1, pp. 18–21].

For the tests, the following parameters were adopted: outer diameter — D = 200 mm; wall thickness — t ≈ 12 mm (SDR ≈ 17); and test section length — L = 1.5 m. The choice of SDR 17 provides a balance between ring stiffness and experimental safety. The SDR value is determined using the following ratio [2, p. 37]:

$$SDR = \frac{D}{t}$$

For HDPE pipes, the elastic modulus (E) and Poisson's ratio (\nu) given in the manufacturer's catalogs were adopted for comparison with design analyses [3, pp. 44].

The experiments were carried out in laboratory conditions using a specially prepared trench model. The trench was constructed in the form of a rigid-walled metal box, which limited lateral wall deformations during loading and ensured more accurate recording of stresses in the soil–pipe system [4, p. 29].

The trench parameters were as follows: burial depth — h = 1,2 m; width — approximately ~1,5 times the pipe diameter; a 5–8 cm sand bedding layer was placed under the pipe.

The soil consisted of a mixed composition (sand + fine clay fraction), and the moisture content was stabilized under laboratory conditions. Compaction was carried out in two stages: partial filling of the side zones with light compaction, followed by final filling up to the surface.

This approach is close to real construction technology and makes it possible to reliably model the interaction between pipe ring stiffness and soil bedding [2, pp. 41–42].

Vertical external loading was applied using a hydraulic press. The load was transferred through a steel plate, providing a nearly uniform distribution over the pipe crown. Such a scheme approximately simulates typical external loads encountered in infrastructure systems, including traffic loads, soil compaction, and temporary loads [5, p. 97].

The load was increased step by step, and at each stage the load value, radial displacement, and ovalization were recorded after stabilization. A short pause was maintained between stages in order to account for the initial effect of time-dependent behavior.

Two main deformation indicators were measured in the study:

Radial displacement (w).

The downward displacement of the pipe crown was recorded using a dial gauge. This indicator is important for assessing the flexibility of the pipe wall [3, p. 52].

Ovalization (\Delta D).

The deviation of the pipe cross-section from a circular shape was evaluated as follows:

$$\Delta D = D_{\text{vertical}} - D_{\text{horizontal}}$$

Here, D_{vert} — the diameter measured in the vertical direction, and D_{horiz} — the diameter measured in the horizontal direction.

An increase in ovalization indicates a decrease in ring stiffness and an intensification of stress concentration in the pipe wall [4, p. 35]. At each loading stage, measurements were repeated at least three times, and the average values were taken.

The obtained data were compiled in tabular form, after which the load–displacement graph (Figure 1) and the load–ovalization graph (Figure 2) were plotted. The inflection points on the graphs were taken as the main criterion for identifying the transition of deformation behavior into the nonlinear zone [1, pp. 77–78]. In addition, the experimental results were compared with theoretical estimates, serving as initial data for calibrating numerical models in subsequent stages.

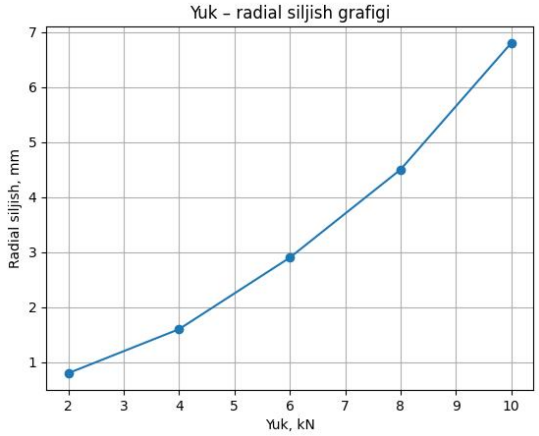


Figure 1. Load–radial displacement graph

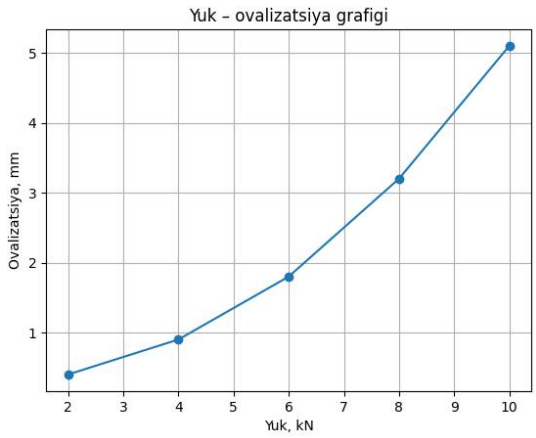


Figure 2. Load–ovalization graph

3. RESULTS

This section analyzes the variation of radial displacement and ovalization recorded during the loading process. The obtained results clearly demonstrate the redistribution of stresses within the soil–pipe system and the gradual reduction of ring stiffness [1, pp. 77–78].

Table data (Table 1) and graphical analysis show that, at low loading stages, radial displacement remains relatively small and the deformation exhibits an almost linear character. At this stage, elastic deformation dominates in the pipe wall, while friction along the side contact with soil has not yet been fully mobilized.

With increasing load, an inflection point appears on the curve. Beyond this point, a noticeable increase in displacement is observed: in the range of 2–4 kN the growth is slow, while after 6–8 kN the increase accelerates, and at 10 kN the maximum values were recorded. This behavior is associated with the redistribution of soil pressure, partial “settling” of the pipe wall, and the beginning of active interaction with the side walls [2, pp. 41–42].

The results indicate that an HDPE pipe does not behave as a rigid structural element, but rather as a flexible system working jointly with the surrounding soil [3, p. 52].

Table 1

Dependence of deformation on vertical load

Load stage	Vertical load (kN)	Radial displacement (mm)	Ovalization (mm)
1	2	0.8	0.4

Load stage	Vertical load (kN)	Radial displacement (mm)	Ovalization (mm)
2	4	1.6	0.9
3	6	2.9	1.8
4	8	4.5	3.2
5	10	6.8	5.1

As can be seen from the table, deformation intensifies progressively with increasing load.

The ovalization curve has a shape close to a parabola: at the initial loading stages, the values are small, while after a certain threshold a pronounced increase is observed. This indicates that the circular cross-section gradually approaches an elliptical form.

The growth of ovalization is associated with a reduction in ring stiffness, an increase in stress concentration in the pipe wall, and the formation of local weak zones [4, p. 35].

In particular, under higher loads, the fact that ovalization increases faster than radial displacement indicates the onset of a significant influence on the shape of the pipe cross-section. From the point of view of structural integrity, this situation may become critical, since distortion of the shape reduces operational safety under pressure conditions [5, pp. 96–98].

The table allows the following conclusions to be drawn: both radial displacement and ovalization exhibit nonlinear behavior with increasing load; although deformation is low at the beginning, once the load threshold is exceeded, a sharp growth is observed — which indicates the need for careful selection of a “safe range” in design; ovalization reacts later than radial displacement but increases rapidly at the critical stage — serving as one of the indicators of structural risk.

The obtained results are consistent with the findings reported by other researchers on HDPE pipes: flexible pipes “share” the load with the surrounding soil [2, pp. 40–45]; nonlinear deformation becomes significantly intensified as the load increases [1, p. 73]; and ovalization accelerates at critical loading stages [4, p. 35]. This confirms that the experimental data can serve as a reliable basis for calibrating numerical models in the subsequent phases of the study.

4. DISCUSSION

The experiments clearly demonstrated that HDPE pipes under trench conditions behave as a flexible system working together with the surrounding soil. As the load increased, the deformation process in the pipe wall manifested itself through several successive stages.

In the first stage (under low loads), the deformation was mainly elastic in nature: radial displacement was relatively small and ovalization was almost negligible. During this period, the lateral support of the soil was not yet fully mobilized, and the pipe ring carried most of the load by itself [1, p. 73].

In the second stage, with increasing load, redistribution of soil pressure, intensification of friction along the side walls, and partial “bearing” of the pipe into the soil were observed. At this point, an inflection appeared on the curve, and radial displacement accelerated. This mechanism is typical for flexible pipes and indicates that a certain part of the load is transferred to the soil [2, pp. 40–45].

In the third stage, at higher loads, a rapid increase in ovalization begins. This is associated with deviation of the pipe cross-section from circularity, reduction in ring stiffness, and local intensification of stresses [4, p. 35]. In particular, deformation concentration may occur in the crown and invert zones, increasing the risk of fatigue and long-term deformation during operation [3, p. 52].

It is worth noting that the nonlinear behavior observed in the results is often underestimated in construction practice. In some cases, limiting the design analysis only to elastic calculations may lead to underestimation of the actual stresses in the pipe wall. Therefore, when evaluating HDPE pipes in trench conditions, the following factors must be taken into account: degree of soil compaction, burial depth, step-by-step loading, and the time factor (creep) [5, pp. 96–98].

The results show that it is incorrect to treat flexible pipes as overly "rigid structures": they share the load with the soil, and therefore safety criteria should be applied not only to the pipe material itself but to the entire soil–pipe system. This approach is consistent with many modern models presented in the literature and is supported by the experimental findings obtained in this study [2, pp. 41–42].

Another important aspect is that once ovalization exceeds a certain critical limit, further increase in load has a much stronger effect on the cross-sectional shape. In pressure pipelines, this may reduce hydraulic efficiency and increase the likelihood of additional stresses at joints. Therefore, ovalization should be considered as one of the serviceability criteria of pipe structures.

Overall, the experimental results confirm several key principles in the design of HDPE pipelines: the soil–pipe system must be evaluated integrally; zones of nonlinear deformation should be identified in advance; and laboratory trench tests provide a reliable basis for calibrating numerical models. At the same time, several limitations of the present study should be acknowledged: loading rate, stability of soil composition, and the limited consideration of time effects partly restrict the degree of generalization. In the future, long-term tests and experiments with different soil types will make it possible to provide a more comprehensive understanding of this problem.

5. CONCLUSION

In this study, the stress–strain state of HDPE pipes with a diameter of 200 mm under trench conditions was investigated on the basis of laboratory experiments. The obtained results showed that the mechanical behavior of the soil–pipe system is a multi-factor and nonlinear process.

Main scientific findings

With increasing load, the values of radial displacement and ovalization increased consistently; however, this growth was nonlinear in nature. The inflection points on the curves indicated a redistribution of soil pressure.

At low loads, the pipe mainly operated in the elastic regime, whereas at higher loads, noticeable elliptic deformation of the cross-section appeared. This was associated with reduction in ring stiffness and intensification of stress concentration.

1. The research results confirmed that flexible HDPE pipes work as load-sharing systems together with the surrounding soil. Therefore, assessment should not be limited only to the strength of the pipe wall, but should be carried out within the framework of the entire soil–pipe system.Comparison of the results with literature data demonstrated their logical consistency and confirmed that laboratory trench tests serve as a reliable source for calibrating numerical models.

Practical significance

The obtained scientific results can be applied in the following practical directions: selection of pipe burial technology; justification of soil compaction level; determination of safety margins; verification of numerical models and design calculations. In particular, the acceleration of ovalization with increasing load indicates the need to identify critical loading ranges in advance during the design process.

Limitations of the study

In this study, soil composition was considered within a limited range, the loading rate was constrained, and the time factor was not fully taken into account. Therefore, generalizing the results to all conditions requires caution.

In the future, it is advisable to continue research in the following directions: experiments with different soil types (sand, gravel, clay); complex tests including internal pressure; investigation of long-term (creep) deformations; calibration and verification of numerical models based on FEM.

In general, the conducted research helped to provide a deeper understanding of the deformation behavior of HDPE pipes under trench conditions and offered important scientific and practical conclusions for design, analysis, and operation.

6. REFERENCES

1. Smith, J. (2019). Underground Plastic Pipes: Mechanics and Design. Springer.
2. Johnson, R. (2020). Plastic Pipe Design and Installation. Elsevier.
3. Brown, D. (2018). Soil–Structure Interaction in Buried Systems. CRC Press.
4. Miller, A. (2017). Ring Stiffness and Deformation of Plastic Pipes. Wiley.
5. Petrov, V. (2021). Engineering of Underground Utilities. MSU Press.
6. Howard, A., & Gumbel, J. (2016). Buried Pipe Design. McGraw-Hill.
7. Watkins, R., & Spangler, M. (2015). Buried Flexible Pipe: Structural Design and Analysis. Iowa State University Press.
8. Ariaratnam, S., & Najafi, M. (2014). Trenchless Technology and Buried Infrastructure. ASCE Press.
9. McGrath, T. (2013). Performance of Thermoplastic Pipes in Soil Environments. Transportation Research Board.
10. International Organization for Standardization. (2018). ISO 11922-1: Thermoplastics pipes — Determination of dimensions and shape. Geneva: ISO.