Study of Strain-Stress Behavior of Non-Pressure Reinforced Concrete Pipes Used in Road Building

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Abstract. The article contains the results of the full-scale tests performed for special road products – large-diameter non-pressure concrete pipes reinforced with a single space cylindrical frame manufactured with the technology of high-frequency vertical vibration molding with an immediate demolding. The authors studied the change in the strain-stress behavior of reinforced concrete pipes for underground pipeline laying depending on their laying depth in the trench and the transport load considering the properties of the surrounding ground mass. The strain-stress behavior of the reinforced concrete pipes was evaluated using the strain-gauge method based on the application of active resistance strain gauges. Based on the completed research, the authors made a conclusion on the applicability of a single space frame for reinforcement of large-diameter non-pressure concrete pipes instead of a double frame which allows one to significantly reduce the metal consumption for the production of one item. As a result of the full-scale tests of reinforced concrete pipes manufactured by vertical vibration molding, the authors obtained new data on the deformation of a pipeline cross-section depending on the placement of the transport load with regard to the axis.

In industrial, civil and transport construction multipurpose pressure and non-pressure pipelines are particularly important. They are utilized as:

- storm water pipes at arrangement of runoff water facilities [1];
- water supply pipes used for transportation of domestic water [2];
- sewage pipes for transportation of waste and industrial water [3];
- drain pipes [4,5];
- pipe culverts laid in highway and railway bodies to pass the existing stream flows [6-8].

The interaction of an underground facility with the surrounding ground mass and the consideration of the influence of loads applied on the ground surface constitute a complicated problem [9]. Currently, due to increasing transport loads, it is necessary to adjust the available computation procedures considering the experimental data based on the research [10-15].

These researches were purported to determine the value and the nature of the distribution of filling ground pressure on reinforced concrete pipes manufactured by the method of high-frequency vertical vibration molding, laid in a trench, depending on the pipeline-laying depth and different types of the transport load applied on the ground surface.
Per GOST 6482-2011 [16], pipes with the diameter of over 1000 mm are reinforced with a double space cylindrical frame. The test pipes have the inner diameter of 1400 mm and are reinforced with a single frame (see figure 1).

![Figure 1. TSP 140.25-1 reinforced concrete pipes with a double and a single frame.](image)

The test reinforced concrete pipes were cylindrical, inserted-joint, with a foot, a circular opening and a stepped mounting face of the sleeve pipe end. The inner diameter was 1400 mm, the wall thickness – 165 mm, the active length – 2.5 m.

Non-pressure reinforced concrete pipes were manufactured with continuous flow-aggregate technology using the method of vertical vibration molding with an immediate demolding of the item from the hard, fine-grained concrete mix of the designed compression strength of class B 30.

All the manufacturing operations for the formation of non-pressure reinforced concrete pipes are performed on equipment from SCHLOSSER-PFEIFFER (Germany). Throughout the production of reinforced concrete pipes, a VARIANT 1500 D universal molding machine was used.

The pipes are reinforced with a single space cylindrical frame manufactured on MVK 450 machine. The wiring of class B500C with the diameter of 6 mm and the pitch of 50 mm is used as a working (spiral) pipe reinforcement. The rods of class A240 with the diameter of 6 mm as used as a longitudinal (distribution) reinforcement.

The test structure was fitted with a spider welded from a metal bracket with a 50-mm shelf fixed in the pipe bottom line. It contained openings to fix anchors of the dial gauges (grade IGM – 0.001, measuring accuracy – 0.001 mm) registering pipe wall deformations. 3 gauges were installed: one to change the shortening of the vertical diameter, and two to elongate the horizontal diameter (see figure 2).

![Figure 2. Layout of measuring instrument installation in the pipeline cross-section.](image)
The strain-stress behavior of the reinforced concrete pipes was evaluated using the strain-gauge method based on the application of active resistance strain gauges. We used strain gauges fitted with a wire loop rack with a base of 20 mm and the resistance of 200 Ohm.

Strain gauge strips were pasted in the most strained sections of the structure (see figure 2): on the vertical diameter in the pipe bottom line and soffit, on the horizontal diameter from the outside.

Each of the 24 pasted strain gauge strips consisted of 5 and 6 gauges totaling 128 pieces. BF-2 glue was used for pasting and damp-proofing of the gauges.

The gauge wires were connected to a MMTC-64.01 microprocessor multichannel strain gauge system developed in the Siberian Research Institute named after S.A. Chaplygin used for reading out and primary processing of the test results.

The test site featured a trench with a 55-m pipeline laid therein (see figure 3). The pipeline was laid one year before the experiment. The trench had the following dimensions: bottom width – 4.93 m, top width – 7 m, depth – 2.775 m, slope angle of the trench wall with regard to the horizontal – 70°.

![Figure 3. Cross-section of the trench without filling (a) and with filling (b).](image)

The experiment was carried out at the estimated height of the pipeline’s ground filling of 1 m (see figure 3a) and 2 m (see figure 3b).

Transport load was set by 3 types of vehicles (see figure 4):

- TOYOTA COROLLA motor car (fully loaded weight 1.65t);
- KamAZ 65115 (fully loaded weight 25.2t);
- BelAZ 7547 mine dump truck (fully loaded weight 85t).
Throughout the experiment, the vehicle crossed the pipeline perpendicular to its axis. As far as the vehicle was moving, the measurements were made in 11 points with the distance of 1 m between them. Figure 5 shows the data of the vertical and horizontal pipe diameter measurement (mm) when tested using a BelAZ 7547 (fully loaded weight 85t) at the ground filling height of 1 and 2 m.

PLAXIS 2D Version 9.0 suite of finite element software was used to model a design circuit considering ground conditions for pipeline laying and to set the transport loads. The software calculation results were used to obtain an isofield of the ground mass deformations and a diagram of bending moments arising in the pipeline. The comparison of the maximum bending moments has shown that the values of the full-scale tests match with the PLAXIS 2D calculations, and the pipes had a strength margin (see table 1). No cracks were formed in the pipe.

| Type of vehicle | Test conditions | Measured parameter | Stage number |
|-----------------|-----------------|--------------------|--------------|
| BelAZ (80 000 kg) | Without filling | BelAZ-Vertical diameter-1 meter | 0,000 | -0.001 | -0.005 | -0.012 | -0.048 | -0.088 | -0.019 | -0.100 | -0.042 | -0.006 | 0.002 | 0.001 | 0.000 |
|                 |                  | BelAZ-Horizontal diameter-1 meter | 0,000 | -0.003 | -0.002 | 0.003 | 0.043 | 0.083 | 0.006 | 0.109 | 0.043 | -0.002 | -0.008 | -0.005 | 0.000 |
|                 | With filling     | BelAZ-Vertical diameter-2 meters | 0,000 | -0.006 | -0.010 | -0.017 | -0.033 | -0.043 | -0.043 | -0.027 | -0.061 | -0.045 | -0.018 | -0.008 | -0.002 | 0.000 |
|                 |                  | BelAZ-Horizontal diameter-2 meters | 0,000 | -0.002 | 0.001 | 0.010 | 0.031 | 0.040 | 0.025 | 0.070 | 0.049 | 0.017 | 0.002 | -0.003 | 0.000 |

**Figure 5.** Pipe diameter diagram at the test using a BelAZ.

**Table 1.** Comparison of the experimental values with the estimated values from the influence of a BelAZ 7547 mine dump truck.

| Mmax measuring method | Max bending moment value, kNm |
|-----------------------|-------------------------------|
|                       | Ground filling height 1 meter | Ground filling height 2 meters |
| Full-scale tests      | 18.955 (100%)                 | 12.998 (100%)                 |
| PLAXIS 2D             | 17.513 (92%)                  | 12.848 (99%)                  |
| SN 00075              | 25.38 (134%)                  | 24.42 (188%)                  |

Note: SN 00075 “Instruction on the Calculation of Underground Pipeline Loads” [17].

The research findings confirmed applicability of a single space cylindrical frame instead of a double frame per GOST 6482-2011 [16] to reinforce large-diameter non-pressure concrete pipes. The comparison of material consumption for the production of one item is shown in table 2. The
reinforcement of concrete pipes with a single cylindrical frame will enable a 49% decrease of metal consumption at a 15% increase of concrete consumption.

Table 2. Material consumption for the production of one item.

| No. of item | Materials  | Single-frame pipe (GOST 6482-88) | Double-frame pipe (GOST 6482-88) |
|-------------|------------|----------------------------------|----------------------------------|
| 1           | Steel      | 55.68 kg (51%)                   | 109.93 kg (100%)                 |
| 2           | Concrete   | 2.3 m³ (115%)                    | 2.0 m³ (100%)                    |

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