Application of Non-pressure Reinforced Concrete Pipes in Modern Construction and Reconstruction of Highways

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Abstract. Modern highway construction technologies provide for the quality water discharge systems to increase facilities’ service life. Pipeline operating conditions require the use of durable and reliable materials and structures. The experience in using reinforced concrete pipes for these purposes shows their utilization efficiency. The present paper considers the experience in the use of non-pressure reinforced concrete pipes manufactured by the German company SCHLOSSER-PFEIFFER under the Ural region geological and climatic conditions. The authors analyzed the actual operation of underground pipelines and effective loads upon them. A detailed study of the mechanical properties of reinforced concrete pipes is necessary to improve their production technology and to enhance their serviceability. The use of software-based methods helped to develop a mathematical model and to estimate the strength and crack resistance of reinforced concrete pipes at different laying depths. The authors carried out their complex research of the strain-stress behaviour of reinforced concrete pipes and identified the most hazardous sections in the structure. The calculations performed were confirmed by the results of laboratory tests completed in the construction materials, goods, and structures test center. Based on the completed research, the authors formulated their recommendations to improve the design and technology of non-pressure reinforced concrete pipes.

1. Introduction

Modern construction and reconstruction of highways requires a quality water discharge system to increase service life and to improve operating conditions. Experience has proven that the most durable pipelines for the transportation of fluids are those made of reinforced concrete pipes. Concrete is one of the most universal, reliable, and cost-effective materials used for storm water and sanitary sewage, as well as irrigation facilities [1-3].

As a result of the application of advanced technologies and design solutions, use of concrete pipes continues growing globally. Designers and standardization services consider them a durable and economically feasible fluid transportation system. Once laid, correctly designed underground pipelines preserve their maintenance-free and cost-free serviceability over the course of many years [4, 5].

Non-pressure concrete pipes were first used in the 1850s in Odessa and Rostov-on-Don. Currently, new technological solutions have appeared in our country which enable the production of non-pressure reinforced concrete pipes in a wide range of diameters; modern plants are built for their production [3, 6].
This paper considers the first stage of work on commissioning of products made with the technology of the German company SCHLOSSER-PFEIFFER as applied to the geological and climatic conditions of the Urals.

Non-pressure reinforced concrete pipes are utilized for the laying of underground pipelines for the repair and construction of highways. They are used for gravity transportation of household fluids and storm waters without filling the entire pipe’s cross-section, as well as for underground water and industrial liquids not corrosive to reinforced concrete and rubber sealing rings.

Two types of reinforced pipes are the most widespread (figure 1):

TS – cylindrical pipe sockets with a stepped mounting face of the sleeve pipe end and abutting joints sealed with rubber rings;

TSP – analogous, but with a foot.

![Figure 1. Design of non-pressure reinforced pipes: a – longitudinal pipe cross-section; b – transverse cross-section of the cylindrical pipe; c - transverse cross-section of the foot-based pipe; d – flexible wiped joint; L – pipe length; Di – inner diameter; t – wall thickness.](image)

2. Production of reinforced concrete pipes using vertical vibration molding with an immediate demolding of the item

In December 2005, a reinforced concrete pipe production plant was commissioned in Chelyabinsk. The monthly capacity of the plant is 3,000 meters of reinforced concrete pipes. Construction, assembling, and commissioning was executed by PKO ChelSI LLC.

This enterprise manufactures non-pressure reinforced concrete pipes 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 (hardness – Zh3).

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 is used (figure 2), consisting of two working shafts installed below the floor level, fitted with two controllable central vibrators (vibration cores) connected to the machine’s core by special clamps, which enables quick replacement of the mold at changing over to a new item.

The outer mold line tool and the metal tray are placed separately from other units of the machine. The tray is a rigid slab with a shell ring imitating a pipe socket. The tray is used as the foundation for all further pipe-manufacturing operations. To prevent cement leakage during pipe molding, a rubber ring is fixed between the outer mold line tool and the tray in the mold groove. The outer mold line tool has one or two pairs of diametrically arranged ears to engage the x-shaped cross head. The cross head, together with the outer mold line tool and the tray, enables transportation of the pipe along the process chain in the vertical position. The cross head consists of an x-shaped frame and four steel rods made in the form of hammered cable chains.
The butt of the sleeve section of the pipe is smoothed by the alternating movement of the shaped ring, which rotation mechanism is activated by the hydraulic drive. The cable-operated overhead traveling crane of Q=10 tons is used to raise the item from the shaft and to remove the mold from the item.

![Diagram](image)

Figure 2. VARIANT 1500 D universal molding machine: 1 – concrete mix receiving bunker; 2 - vibrators; 3 - mold; 4 – main platform; 5 – concrete supply rotary table; 6 – belt conveyer; 7 – rotary filling conveyer; 8 – bearing frame; 9 – sleeve-part molder portal.

The concrete mix is prepared in the planetary concrete mixing machine of V=1.5/1m³. The concrete mix is laid in the mold by the concrete placer with a movable conveyer belt.

The longitudinal rods of the reinforcing cage are made on an SPR-12 straightening and cutting machine. Cylindrical reinforcing cages for pipes are made on an MVK 450 MASCHINENBAU GMBH specialized and automatically-operated machine for welding closed cages. Handling operations are performed in the assembly shop by two overhead cranes of Q=2 tons. The completed pipes are handled and canted by a Linde P140 fork-lift truck with round jaws of Q = 14 tons.

3. Study of the stress-strain behavior of non-pressure reinforced concrete pipes

We analyzed the actual operating conditions of pipelines and loads upon them to obtain high-quality products suitable for application in the geological and climatic conditions of the Ural region [7, 8].

Such a detailed study of the mechanical properties of reinforced concrete pipes and their manufacturing technologies and the development of methods to calculate the strength and crack resistance were necessary for design engineering of reliable and cost-efficient pipelines [9,10].

In this case, the problem was implemented in the Lira 9.2 software suite based on a simulation model with a constant coefficient of subgrade reaction (Winkler foundation).

The calculation model of the reinforced concrete pipe is divided into 290 plate-like finite elements 50x100mm (KE 41-universal rectangular jacket element) and 319 units. The elements are set by two types of hardness.

The pipe foundation is modeled by elements with the set coefficient of ground reaction:
- for sand – C=70•10³ kN/m³;
- for clay – C=250•10³ kN/m³;
- for rocky soil – C=1000•10³ kN/m³.

The designed reinforced concrete pipes have the following mechanical characteristics: concrete class B30, elasticity modulus E=26000 MPa, Poisson’s ratio 0.2. Let us consider concrete to be isotropic and elastic.
Loads on the designed pipeline are adopted based on the results of the statistical calculation [11].
The design model consists of 5 loadings (figure 3):
Loading 1 – gravity load;
Loading 2 – load from vertical ground pressure;
Loading 3 – load from horizontal ground pressure;
Loading 4 – vertical ground pressure from NK-80 temporary load;
Loading 5 – horizontal ground pressure from NK-80 temporary load.

![Figure 3](image)

**Figure 3.** Cumulative loads on the structure: a – loads acting on the structure from vertical and horizontal ground pressure; b - vertical and horizontal ground pressure on the structure from NK-80 temporary load (at 4-meter estimated height of ground filling).

We consider all the materials of this model to be solid and have constant mechanical properties. This assumption enables us to consider stress, deformation, and shifting of individual points as continuous functions of coordinates. In addition, we consider the materials to be elastic, therefore, we can solve the problem within the framework of the linear elastic theory [12,13].

As a result of the research in the Lira 9.2 software suite, we developed 9 design models of a pipe segment with an inside diameter of 400mm depending on the estimated height of ground filling: 2m, 4m, 6m, and the bedding: sand, clay, rock (figure 4).

![Figure 4](image)

**Figure 4.** Example of a calculation result: stress isofield by Nx (estimated height of ground filling 4 meters, bedding - clay).

If we compare the pipe deformations depending on the estimated height of ground filling (figure 5), we find that the vertical diameter changes more than the horizontal [14]. At 6-meter estimated height of ground filling deformations of the reinforced concrete pipe are approximately 1.2 times more than those at 4 meters, and 1.8 times more than those at 2 meters.
The calculation results allowed us to set dependencies of the numerical values of sinking on the estimated height of ground filling and the bedding type (figure 6): in case of sand it is 3.5 times more than clay, and 15 times more than rocky soil [15].

Table 1 shows stresses in the structure caused by the combined action of the dead weight of the ground mass and the temporary load of NK-80 machine.

The stresses influencing the structures significantly depend on the height of the estimated ground filling layer [16,17]. At a 6-meter depth of ground filling they are approximately 1.3 times more than at 4 meters, and almost twice more than at 2 meters.

Table 1. Stresses influencing the structure (bedding – clay).

| Indicators     | Estimated height of ground filling |
|---------------|-----------------------------------|
|               | 2 meters  | 4 meters  | 6 meters  |
| Movements along X, mm | -1,14 | -1,03 | -1,7 | -1,53 | -2,14 | -1,94 |
| Movements along Y, mm | -0,0478 | 0,0474 | -0,0732 | 0,0727 | 0,0872 | 0,0865 |
| Stresses Nx, t/m² | -60,9 | -8,75 | -91,2 | -12,1 | -116 | -21,3 |
| Stresses Ny, t/m² | -7,83 | 2,69 | -11,4 | 4,1 | -15,6 | 5,15 |
| Stresses Txy, t/m² | -6,79 | 6,78 | -10,2 | 10,2 | -12,8 | 12,8 |
| Stresses Mx, t*m/m | 0,185 | -0,172 | 0,262 | -0,282 | 0,34 | -0,316 |
| Stresses My, t*m/m | 0,0376 | -0,0354 | 0,0572 | -0,0538 | 0,0689 | -0,065 |
| Stresses Qx, t/m | -1,86 | 1,85 | -2,81 | 2,81 | -3,41 | 3,41 |
| Stresses Qy, t/m | 0,215 | -0,215 | 0,326 | -0,326 | 0,401 | -0,4 |

4. Laboratory Testing
Pipe strength, crack resistance, and water impermeability tests were carried out in the construction materials, goods and structures test center of the Academician V.P. Makeev State Rocket Center per the procedure described in GOST 6482-2011 Reinforced concrete nonpressure pipes. Specifications. [18-20] (figure 7).

The Lira 9.2 software suite was also used for a machine experiment aimed at identifying the most hazardous places in the structure (figure 8).
The nature of the pipe’s stress-strain behavior obtained at calculation by the developed design model (figure 4) was confirmed by laboratory tests. Testing showed that reinforced concrete pipes produced by PKO CheSI LLC with technology from the German company SCHLOSSER-PFEIFFER have a strength and crack-resistance margin.

5. Conclusions
1. Using the Lira 9.2 software suite we developed a design model and calculated the strength and crack resistance of reinforced concrete pipes at differed laying depths;
2. We completed a complex study of the strain-stress behavior of reinforced concrete pipes and identified the most hazardous sections in the structure;
3. The previously stated calculations were confirmed by the results of the laboratory tests carried out in the construction materials, goods and structures test center of the Academician V.P. Makeev State Rocket Center;
4. Based on the research completed, the authors organized the batch production of non-pressure reinforced concrete pipes at the Production and Commercial Association Chelyabinsk-Stroyindustria, LLC. construction material plant. To date, this type of reinforced concrete pipe structure has been used in road building while reconstructing the road Svoobody st. in Chelyabinsk and construction of the M-5 Moscow – Ufa federal highway.
5. The authors have developed a legal framework to organize construction operations: together with VNIIzhelezobeton OJSC (Moscow), they developed and implemented specifications for this type of product in design engineering and construction practice.

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