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# Calculation and Designing of Reinforced-Concrete Non-Pressure Pipes with Inner Lining

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This article presents the results in the research of the load-carrying ability of reinforced-concrete non-pressure pipes with inner lining intended to protect concrete against corrosion. The lining (covers) are mounted as a stay-in-place formwork when manufacturing the pipes. The covers are made of 3-5 mm thick polyethylene sheets. To be fixed in the pipe wall concrete, the linings are provided with special anchoring elements. Two lining types are considered: 1 – with anchoring elements in the form of solid longitudinal ribs; 2 – with anchoring elements distributed equidistantly over the shell surface (≈400 pcs/m$^2$).

The research has been performed by numerical simulation using a three-dimentional finite element model. The load was applied according to a three-linear pattern used to test pipes for strength (including that specified in EN 1916). The computation was performed by the iteration method taking into account physical non-linearity of concrete. The computation makes allowance for formation and opening of cracks in the longitudinal pipe wall sections. The examples of computation of a pipe with the diameter of 2,000 mm and wall thickness of 150 mm reinforced with two cylindrical cages and a pipe with the diameter of 1,000 mm and wall thickness of 110 mm reinforced with a single cylindrical cage are given. It has been determined that the load-carrying ability of pipes with type 1 protective linings is lower than that of pipes with type 2 linings. Maximum (up to 25%) reduction of the load-carrying ability is observed in pipes reinforced with a single cylindrical cage. In pipes of this type, cracks are formed at lower loads. The load-carrying ability of pipes is reduced due to entering of anchoring ribs of the protective shell into the compression zone of the pipe wall concrete in the sections located at the level of the horizontal diameter. The results of the numerical computation are in good agreement with those obtained when testing full-scale specimens of pipes with specified technical parameters.

To protect interior faces of reinforced-concrete non-pressure pipes, it is recommended to use lining covers with V-type discrete anchoring members ensuring reliable mechanical fixing of the linings in the pipe wall concrete. This type of anchoring elements causes almost no effect upon the load-carrying ability of pipes.

**KEYWORDS:** experimental investigation, load-carrying ability, numerical simulation, protective lining, reinforced-concrete pipes.

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## Introduction

The condition survey of sanitary sewage conduits made of reinforced-concrete non-pressure pipes has shown that some of the conduits are operated under exposure to aggressive biologically active media. Here the corrosion attacks exposed concrete surfaces of the conduit arch, where thionic bacteria colonies settle. Under the said conditions, service life of the conduits is shortened down to 25...30 years and sometimes to 10...15 years [Shepelevich 2000]. The most reliable method to protect concrete against corrosion consists in lining of the structure surfaces with corrosion-resistant material. To protect the inner cavity of pipes when manufacturing them by the vibrocompression method, it is very efficient to use polyethylene covers as a stay-in-place formwork.

The covers are manufactured of 3-5 mm thick polyethylene sheets by welding them into a "stocking". To ensure fixing of the cover in the pipe wall concrete, one of the sheet surfaces is provided with special anchoring elements. Two types of lining sheets are in use: those with anchoring elements in the form of solid ribs spaced with the pitch of 30-50 mm, see Fig. 1a; and those with discrete anchors distributed equidistantly over the sheet surface (≈400 pieces per 1 $m^2$), see Fig. 1b. The height (penetration into concrete) of anchoring elements is 13-15 mm.

Round-section reinforced-concrete non-pressure pipes are reinforced with cylindrical reinforcement cages. Thus, reinforced-concrete pipes as per GOST 6482-88 with the diameter of less than 1200 mm are reinforced with a single cylindrical reinforcement cage to be mounted in the middle cross-section of the pipe wall. Pipes with the diameter of more than 1200 mm are reinforced with two cylindrical cages mounted at the interior lateral face and exterior lateral face of the pipe [GOST 6482]. Poor physical and mechanical characteristics of polyethylene do not allow its combined action with concrete to be taken into account and the effective thickness of such pipes is reduced by 4-5 mm as compared to the initial thickness. The effective height of the cross-section is reduced as well. If solid anchoring ribs occur in the concrete compression zone, both strength and crack resistance of the pipe wall are reduced significantly. It appears to be the most relevant for pipes with a single reinforcement cage.

The objective of the research is to develop a method for calculation of reinforced-concrete non-pressure pipes with protective lining for strength and crack resistance.

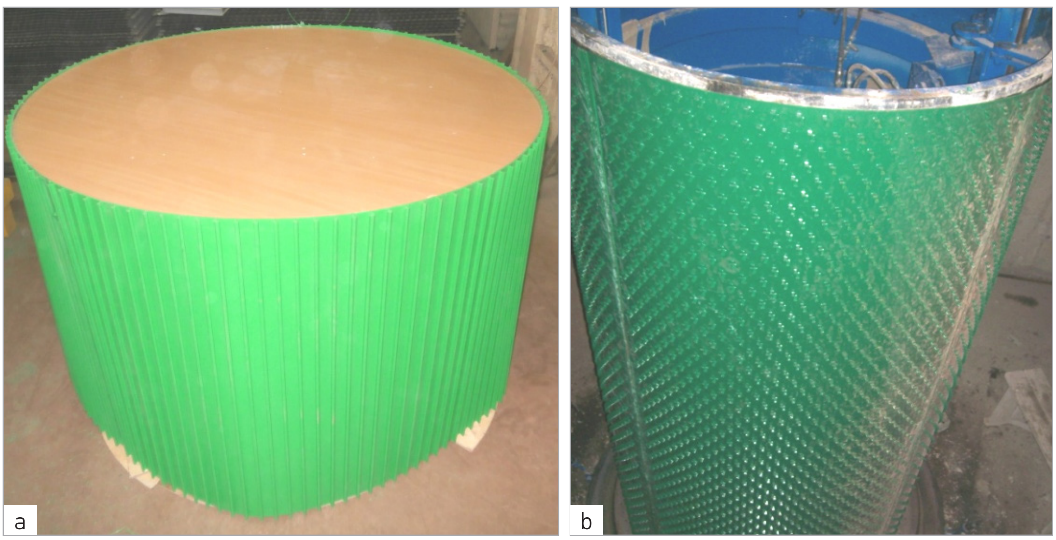


Fig. 1

Inner linings (general view): a) with anchoring elements in the form of solid longitudinal ribs; b) with anchoring elements distributed equidistantly over the shell surface

## Method

The loading tests of pipes were performed according to a three-linear pattern specified in EN 1916 (see Fig. 2). Similar patterns are also used in the methodology of calculation of the pipes for strength and crack resistance [Tevelev 2004].

The bending moment diagram in analysed pipe cross-sections is alternating. In the bottom line and crown, the tensile stresses appear on the inner edge of the longitudinal sections of the pipe wall where the lining is located. As

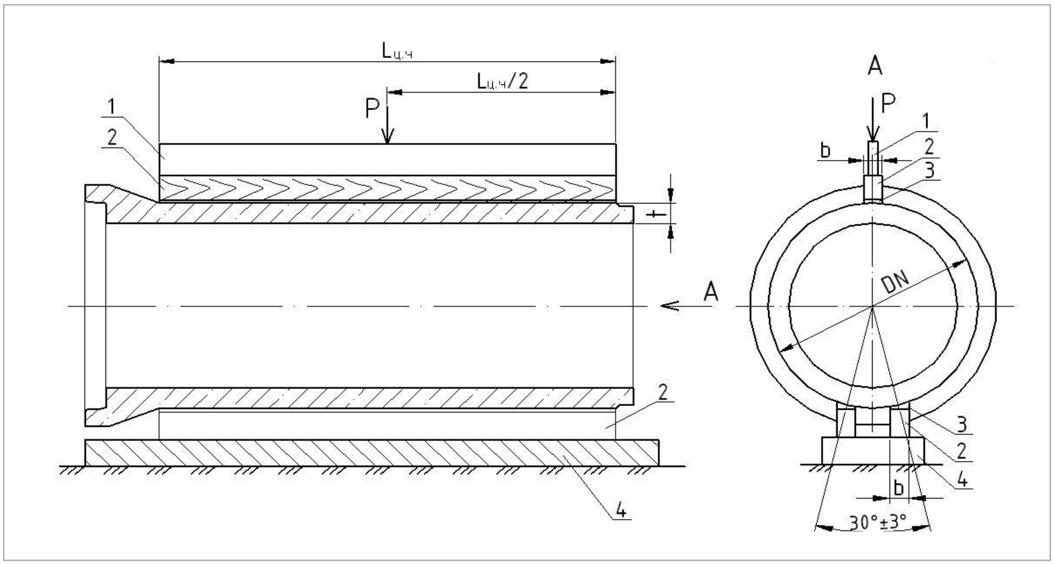


Fig. 2

Test set-up for round-section pipes.
1 – rigid steel beam;
2 – wooden beam, b=100 mm; 3- rubber seals or cement-sand grout;
4 – foundation

regards the sections located at the level of the horizontal diameter, the lining and its anchoring elements fall into compression zone. If the lining is made of polyethylene with initial elasticity modulus of below 1000 MPa and its anchoring elements are made as solid ribs, strength properties of the sections are reduced significantly.

It appears to be the most relevant for reinforced-concrete pipes with a single cylindrical reinforcement cage. The loading tests of these pipes showed that the load-carrying ability of the pipes was depleted due to destruction of the pipe wall longitudinal sections located at the level of the horizontal diameter. The longitudinal ribs of the protective lining in these sections are located in the concrete compression zone. At a certain level of stresses, the lining made of plastic material begins to be "pressed out" from concrete leading to overall growth of compression strain and increase of tensile stresses in the spiral reinforcement of the cage.

The strength and crack resistance of reinforced-concrete pipes with protective lining can be determined by numerical simulation using a finite element model. We used a similar approach for computing the width of the opening of cracks in reinforced-concrete non-pressure pipes [Shepelevich 2012]. Fig. 3 presents a fragment of the finite element model of a reinforced-concrete non-pressure pipe with the diameter of 1,000 mm and wall thickness of 110 mm, belonging to the third group as regards the load-carrying ability. The pipe is reinforced with a single cylindrical cage with S500 working (spiral) reinforcement having the diameter of 8 mm and wound with the pitch of 80 mm. The cage is mounted at the level of the middle surface of the annular section of the pipe. Concrete grade is C25/30.

5x5x5 mm volumetric elements connected rigidly with one another are used to simulate the concrete; bar elements with the length of 5 mm connected rigidly with one another and with volumetric elements (at the nodes) are used to simulate, see Fig. 3.

Deformation characteristics of the elements are specified by stress-deformation diagrams of concrete and reinforcement, see Fig. 4. The data are based on the results of tests of concrete prisms in accordance with GOST 10180-90 and fragments of steel bars.

The lining is specified by volumetric elements connected rigidly with concrete elements at the level of the anchoring rib head only.

For solving this problem the computational software packages MSC/Nastran, taking account of physical and geometrical non-linearity, can be used.

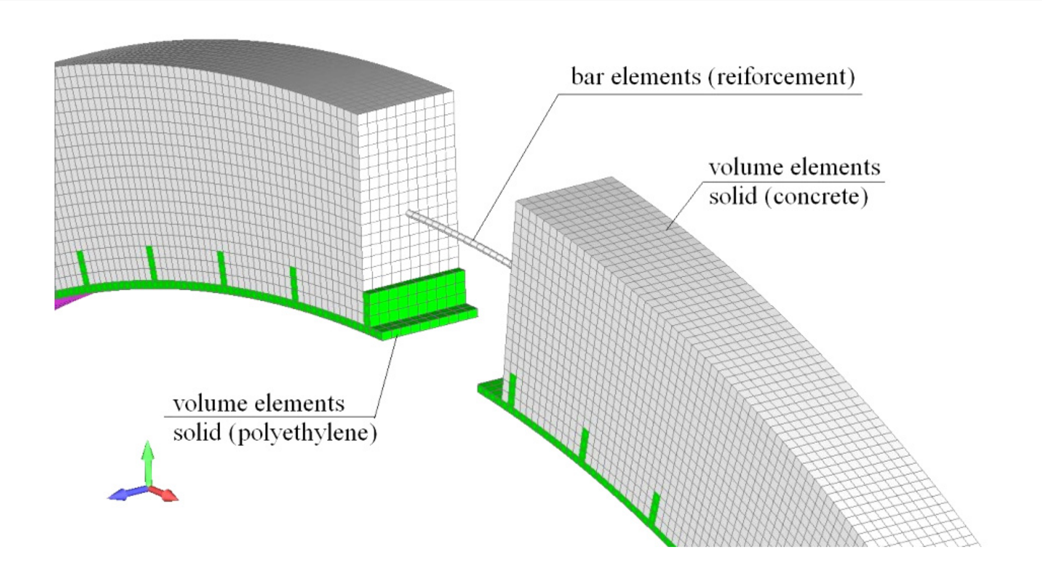


Fig. 3

Fragment of the finite element model of the pipe

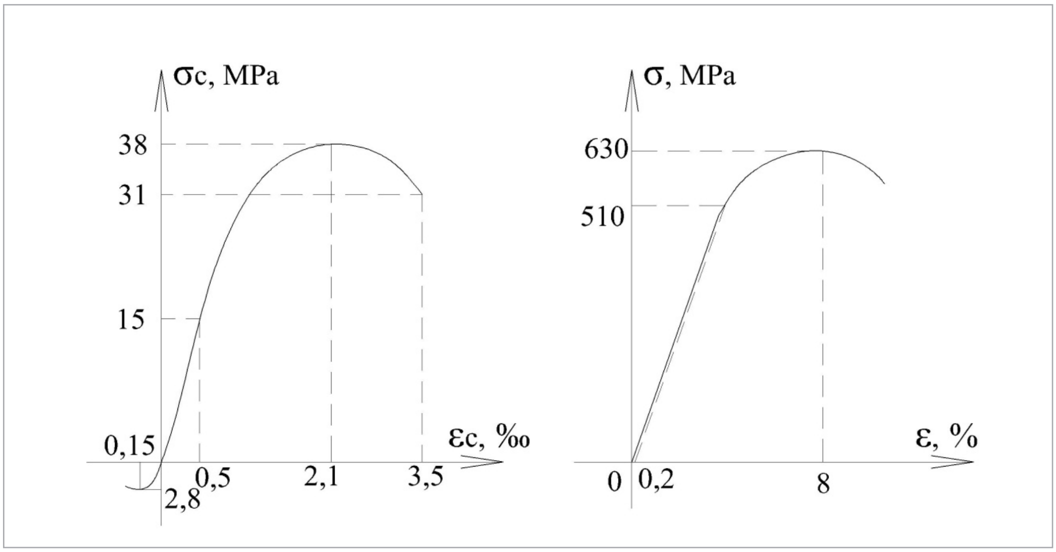


Fig. 4

Stress-deformation diagrams of concrete and reinforcement

Fig. 5 presents the finite element model of the fragment of a reinforced-concrete pipe with inner lining. The fragment width is assumed to be equal to the spiral reinforcement pitch (the cross-section is reinforced with a single spiral). The external load is specified in the form of concentrated vertical forces applied at the model nodes. The fixation conditions were simulated using hinged movable supports and hinged supports arranged according to the test pattern.

The following models of pipes with interior protective lining (for two types of anchoring elements) and without lining were calculated using numerical simulation:

- Ø1000 mm, wall thickness t = 110 mm, reinforced with a single cylindrical cage;
- Ø2000 mm, wall thickness t = 150 mm, reinforced with two cylindrical cages, with and without inner lining.

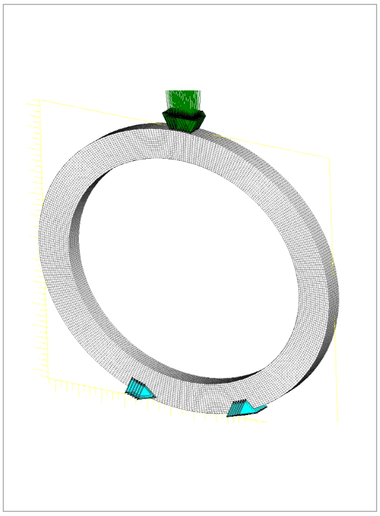

Fig. 5

General view of the finite element model of the pipes in MSC/Nastran

## Results and discussion

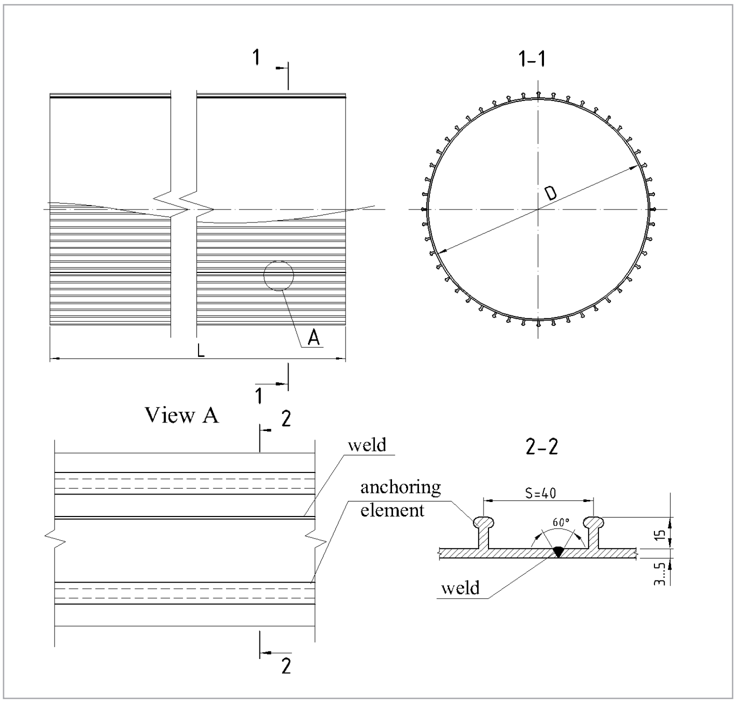


Fig. 6

Scheme of inner linings with anchoring elements in the form of solid longitudinal ribs (type 1)

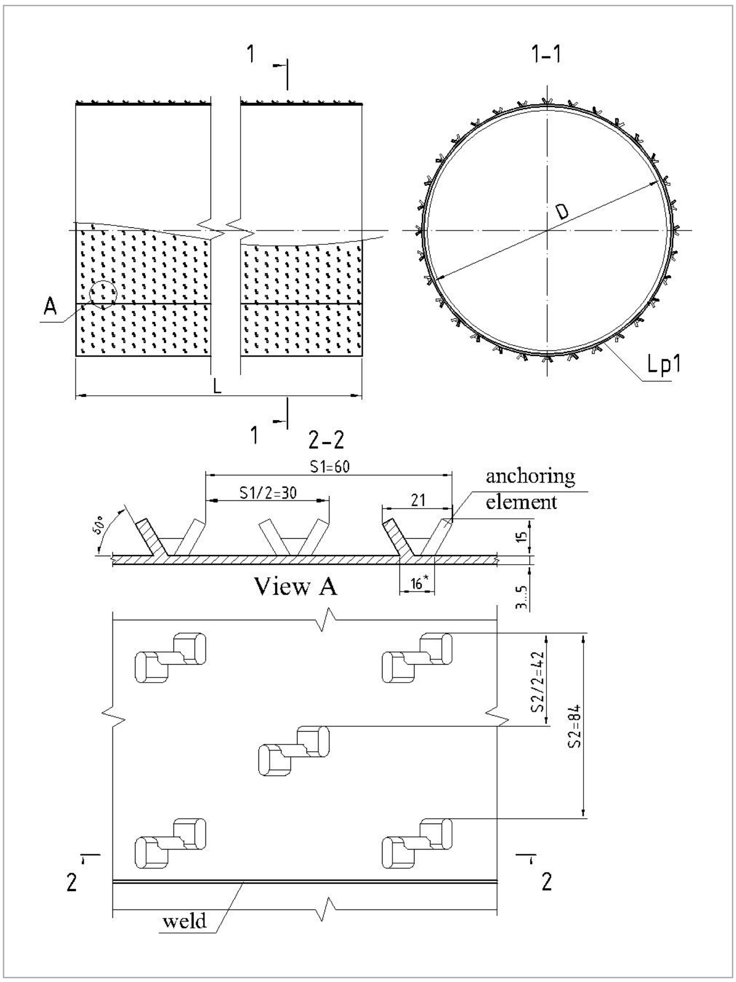


Fig. 7

Scheme of inner lining with anchoring elements distributed equidistantly over the shell surface (type 2)

The schemes of inner linings of both types of anchoring elements are presented in Fig. 6 and 7.

The load was applied in steps adopted for pipe testing. At each step of loading, concrete elements with tensile deformations exceeding the limit of ≈0.15‰ (obtained in an experimental way) were removed and recalculation was performed.

Fig. 8-10 present mosaics of stresses arising in unsafe cross-sections of pipes with the diameters of 1000 and 2000 mm at various steps of loading. The calculation results are presented for pipes without lining and with type 1 protective lining (with anchoring elements in the form of solid longitudinal ribs).

It is to be mentioned that the article doesn't provide the information on calculation results for pipes with the second-type covers as deformations in those pipes are identical to the calculation results for pipes without protective lining. The discrepancy between the results is less than 3% and is due to the reduction in wall thickness by 3-5 mm (the thickness of protective lining).

For the purpose of comparative analysis, the test samples of reinforced-concrete pipes with the diameters of 1000 mm and 2000 mm with protec-

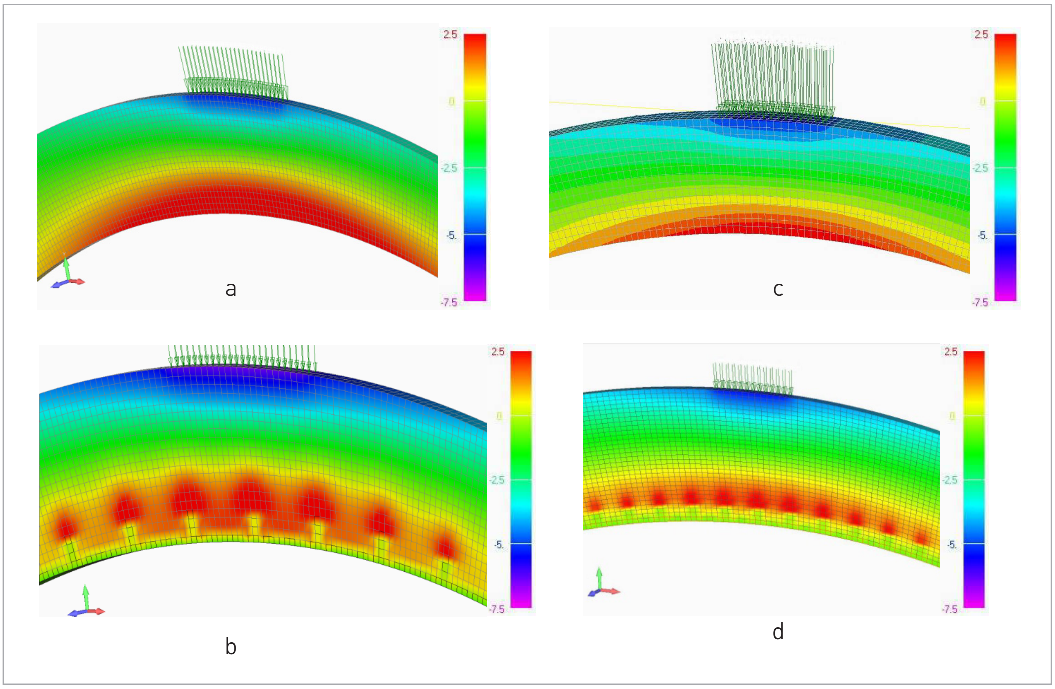


Fig. 8

Stress pattern in the crown of the pipes:
a) load of 46.4 kN/m applied to the Ø1000 pipe without protective lining;
b) the same with lining (E = 1000 MPa); c) load of 95.5 kN/m applied to the Ø2000 pipe without protective lining; d) the same with lining (E = 1000 MPa)

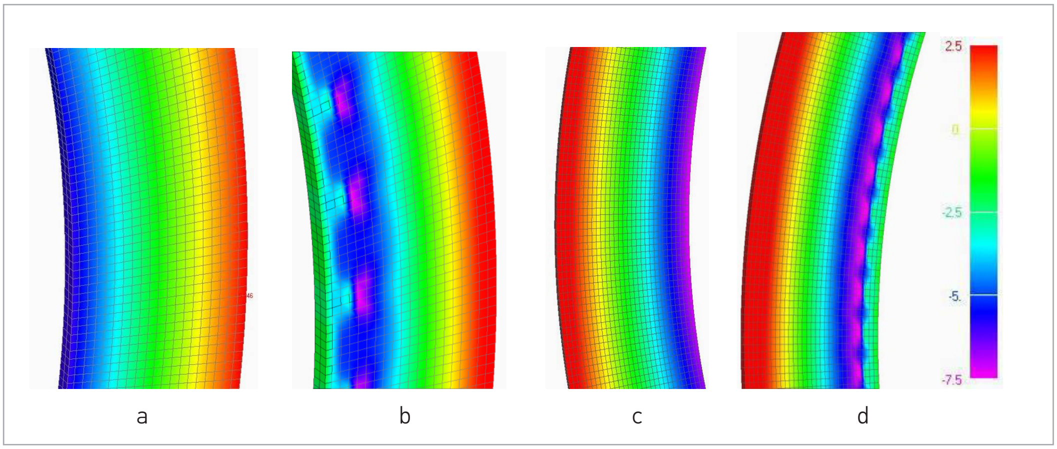


Fig. 9

Stress pattern on the lateral face of the pipes:
a) load of 46.4 kN/m applied to the Ø1000 pipe without protective lining;
b) the same with lining (E = 1000 MPa); c) load of 95.5 kN/m applied to the Ø2000 pipe without protective lining; d) the same with lining (E = 1000 MPa)

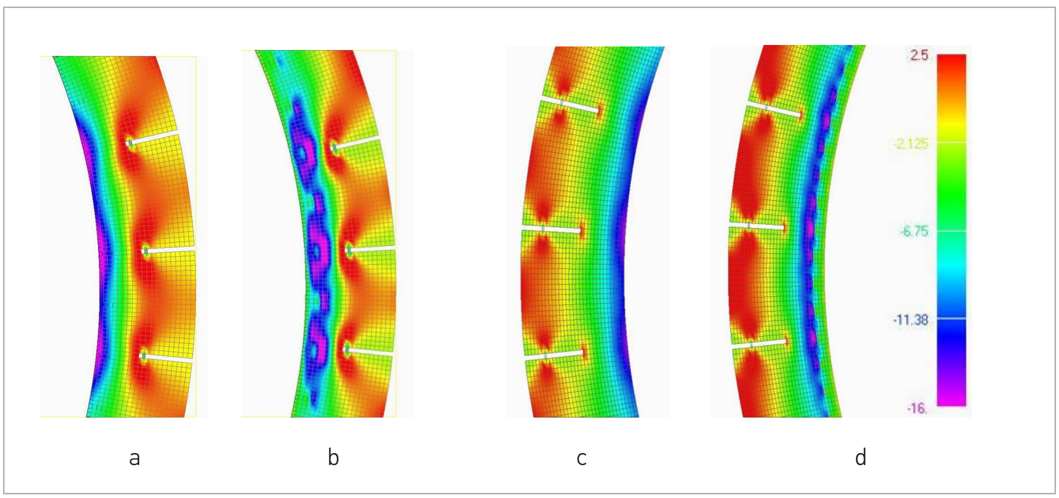


Fig. 10

Formation of cracks and stress pattern on the lateral face of the pipes:
a) load of 72.5 kN/m applied to the Ø1000 pipe without protective lining;
b) the same with lining (E = 1000 MPa); c) load of 138.8 kN/m applied to the Ø2000 pipe without protective lining; d) the same with lining (E = 1000 MPa)

Fig. 11

Testing of the pipe of the PS 100.25-3 cr grade with lining: a) appearance of the tests of a reinforced-concrete pipe; b) nature of destruction of the pipe wall longitudinal section located at the level of the horizontal diameter.

tive polyethylene lining (type 1) and without lining were tested for strength and crack resistance. The pipe with the diameter of 1000 mm is reinforced with a single longitudinal spiral cage and the pipe with the diameter of 2000 mm is reinforced with two cages. S500 reinforcement is used as a working (spiral) reinforcement. The loading tests of the pipes were performed according to the three-linear pattern (see the photo in Fig. 11). The loading was applied in steps. At each step of loading, changes in the vertical diameter and horizontal diameter of the pipe as well as changes in the width of opening of cracks in the crown and on the lateral face at the level of the horizontal diameter were measured.

The appearance of the tests of reinforced-concrete pipe with the diameter of 1000 mm with interior protective lining and the nature (after stripping) of destruction of the pipe wall longitudinal section located at the level of the horizontal diameter is presented in the photos (Fig. 11).

The tests have shown that the formation of cracks on the lateral face in a pipe with the diameter of 1000 mm with lining takes place at lower loads than in the pipe without lining. In addition, reduction of the load-carrying ability of the pipe with the diameter of 1000 mm with lining (type 1) is up to 25% as compared to the reinforced-concrete pipe with the diameter of 1000 mm without lining. In this case, destruction of the pipe with lining takes place due to crushing of concrete in the compression zone at the level of the horizontal diameter (see the photo in Fig. 11b). Destruction of the pipe without lining takes place due to yield of spiral reinforcement in the crown zone.

For Ø2000 mm pipes reinforced with two reinforcement cages, the load-carrying ability of the pipe with lining is reduced by not more than 8% as compared to the pipe without lining.

Table 1 presents the comparative results of the calculations and experimental data of the tests of reinforced-concrete non-pressure pipes with the diameter of 1000 and 2000 mm at various steps of loading for the pipes without lining and with lining with anchoring elements in the form of solid longitudinal ribs (type 1). The actual technical characteristics of the experimental pipes are presented in Table 2.

Table 1

Comparative results and experimental data for the pipes with the diameter of 1000 and 2000 mm

| Assessment criterion | Load in kN/m | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Test sample | | | | Computed model | | | |
| | Ø1000 without lining | Ø1000 with lining (type 1) | Ø2000 without lining | Ø2000 with lining (type 1) | Ø1000 without lining | Ø1000 with lining (type 1) | 2000 without lining | Ø2000 with lining (type 1) |
| Formation of cracks | 69.4 | 57.9 | 138.7 | 130.6 | 68.2 | 56.1 | 131.5 | 122.7 |
| Destruction | 124.8 | 103.1 | 246.1 | 232.5 | 120.7 | 99.7 | 241.5 | 217.2 |

Table 2

Technical characteristics of the test samples of the pipes

| Pipe grade | Diameter Dn, mm | Wall thickness t, mm | Effective depth d, mm | Reinforcement diameter and pitch, mm | Actual strength of concrete, MPa | Actual strength of reinforcement, MPa | Lining type |
|---|---|---|---|---|---|---|---|
| PS 100.25-3 | 1000 | 110 | 55 | 8 x 80 | 39.2 | 630 | --- |
| PS 100.25-3cr | 1002 | 109 | 54 | | 38.5 | 640 | 1 |
| PS 200.25-3 | 2000 | 150 | 120 | 10 x 75 | 38.6 | 630 | --- |
| PS 200.25-3cr | 2002 | 149 | 120 | | 38.3 | 630 | 1 |

## Conclusions

1 The reduction of the load-carrying ability of reinforced-concrete pipes with protective polyethylene lining of the first type (with anchoring elements in the form of solid longitudinal ribs) is caused by falling of the anchoring ribs of the lining into the concrete compression zone of the pipe wall in the cross-sections located at the level of the horizontal diameter.

2 To ensure the corrosion resistance of reinforced-concrete non-pressure pipes, the interior protective lining of the second type with the discrete anchor elements should be used. The application of the lining with anchoring elements in the form of solid longitudinal ribs is only allowed in thick-walled piped reinforced with two cylindrical cages.

3 To calculate the strength and crack-resistance of reinforced-concrete non-pressure pipes with interior protective lining with anchoring elements in the form of longitudinal ribs, it is recommended to use the numerical methodology stated in this article.

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