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INFLUENCE OF GROUND CONDITIONS ON MECHANICAL CHARACTERISTICS OF FIBER-CONCRETE SEWER PIPES

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Abstract- Underground sewer reinforced concrete pipes of large diameter are subject to accidents and deform. Therefore, fiber-reinforced concrete pipes and their stress-strain state under the action of seismic load and soil settlement are investigated in the work. The structure is modeled in PLAXIS 2D and 3D software. These programs are based on the finite element method. In plane and spatial problems, respectively, triangular and tetrahedral finite elements were used. In each finite element, 15 nodes (for a triangular element) and 10 nodes (for a tetrahedral element) were used. The values of stresses and strains in the pipe are determined from the action of a seismic load acting perpendicular to the longitudinal axis of the pipe and soil settlement under the pipe. The study of the strength and crack resistance of underground pipelines showed that with an increase in the diameter of the pipes, the influence of the horizontal component of the seismic load is the cause of the failure of the pipes. Therefore, the manufacture of pipes from fiber-reinforced concrete and the strengthening of the soil base under the pipeline is an important engineering task. The mechanical characteristics of the fiber-reinforced concrete material, such as the modulus of elasticity, Poisson's ratio, tensile resistance, were determined in the laboratory, and then taken into account in the calculation program.

Keywords: Fiber Concrete, Pipe, Stress, Strength, Tension.

1. INTRODUCTION

Underground sewer pipes made of reinforced concrete are made up to 2 meters long, with a diameter of 600 mm to 3000mm by vertical vibro-compression on special equipment. With an increase in the diameter of the pipeline, the double reinforcement of the pipe creates inconvenience in concreting and contributes to the appearance of cracks on the surface of the pipe and further emergency (Figure 1). The pipeline is affected by the load from the roadbed, the weight of the bulk soil, the load from the transport on the road surface, the settlement of the soil under the structure, as well as the seismic movement of the soil mass (Figure 2) [1-3]. The use of fiber-reinforced concrete significantly increases the crack resistance of the pipe, reduces the manufacturing time, and facilitates the concreting process. In practice, both metal and polypropylene fibers are used, which increase the tensile strength of concrete.

2. RESEARCH OF STRESS-STRAIN STATE OF THE PIPE

In engineering design underground reinforced concrete sewer pipes are accepted rigid and non-deformable. Transverse influence of soil is not considered [3]. It is necessary to take into account the weight of pipe, the water weight inside pipe, the specific weight of material of pipe and water in it in pipeline structure calculations. The self-weight of pipe and the weight of the water is calculated by the appointed sizes and the specific weight of the material of pipe and water. The vertical pressure is accepted in the form of uniformly distributed load and the weight of filling in the hollows of the top arch. Static calculation of the reinforced concrete pipes is made in an elastic stage by method of forces as three times statically indefinable closed ring. The ring is calculated separately on each type of load, and then algebraically summarize efforts from these or those loads depending on the accepted their combination. The maximum bending moment in the section of a pipe is influential in the highest and lowest point. To simplification the static calculation all the acting forces can be brought to two opposite acting loads. Loads in calculations are adjusted by the coefficients given in normative documents. It generally belongs to pipes of middle and small diameter (less than Ø1600mm). The arising tension is widespread unevenly and depends on a tilt angle of the influence changing from 0 to 2π. Forces entering the pipe act in a dispersed form (P_i) and depend on the transfer of the pipe into the ground [6]:

$$P = \beta \sum P_i \quad (1)$$

where, β is the coefficient indicating the shape of the pipe transfer to the soil (β<1). The following calculation was performed using the Equation (2) [6]:

$$P_i = 0.325 \times H \times \gamma (1 - 0.06H) \times (d + 0.8) \quad (2)$$

Numerous studies show that if these tubes are tested under press, compression strength and maximum depth underground can be determined.

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Figure 1. Underground sewer pipe accidents

As a result, a fracture and fracture of the pipe occurs, during which the tension strength of the tension material passes. This stress is expressed by the Equation (3) [6]:

$$\sigma_r = 0.0064 n^2 \frac{P}{d} \tag{3}$$

where, σ_r is ultimate strength at magnification; P is a destructive force; d is a diameter of pipe; and ratio of n is a pipe diameter to wall thickness (δ) ($n = d/\delta$).

The tubes form varying internal forces in the tube of seismic load affecting the width of the peak. These internal forces depend on the load angle (φ), the diameter of the pipe. The larger the diameter of the pipe, the greater the effect of the seismic load on the width of the pipe on pipes with a diameter of 1000 mm or more. The scattering of the seismic wave in the pipe in the X-Y coordinate area is taken in a triangular manner. The motion of the soil particles generated by the seismic wave creates a friction force (f_τ) between the soil and the pipe. This force can be defined by the Equation (4) [3, 5]:

$$f_\tau = \pi D (k_\tau \rho_\tau v_{\max} V_k + C_r) \tag{4}$$

where, the φ parameters r, γ_r, C_r are selected from the Table 1 by soil type. Pressure factor depends on earthquake intensity, pipe diameter, pipe wall thickness and soil type. In an elastic environment, the velocity of the waves affecting the neck (V_p) and width (V_s) [6]:

$$V_p = \sqrt{\frac{E(1-\mu)}{\rho_\tau (1+\mu)(1-2\mu)}}$$
$$V_s = \sqrt{\frac{E}{2\rho_\tau (1+\mu)}} \tag{5}$$

They are related to each other:

$$\frac{V_p}{V_s} = \sqrt{\frac{2(1-\mu)}{1-2\mu}} \tag{6}$$

where, ρ_r is soil density; E is a modulus of elasticity; and μ is the Poisson ratio.

Table 1. Physical-mechanical characteristics of soils

Soil type	γ_r, N/m^3	C_r, kPa	φ_r, deg.
Sand	25000	0-2	36-40
Medium density sand	23000	1-3	33-38
Fine sand	21200	2-5	30-36
Sand in powder	20500	2-7	28-34
Sandy loam	19700	4-12	21-25
Loam	19000	6-20	17-22
Clay	16800	12-40	15-18

The total stress in the pipe from the pressure of a seismic wave is determined by the σ_x^s stress and σ_y^s total stress [6]:

$$\sigma^s = (\sigma_x^s + \sigma_y^s) K_\perp$$
$$\sigma_x^s = \frac{\min(F_k, F_\tau)}{A} \tag{7}$$
$$\sigma_y^s = \frac{M_k}{W}$$

where, $K_\perp$ is the coefficient of design pressure of seismic force perpendicular to pipeline. This factor is determined by the ratio of seismic stresses of width to stresses arising from seismic forces of the neck and width.

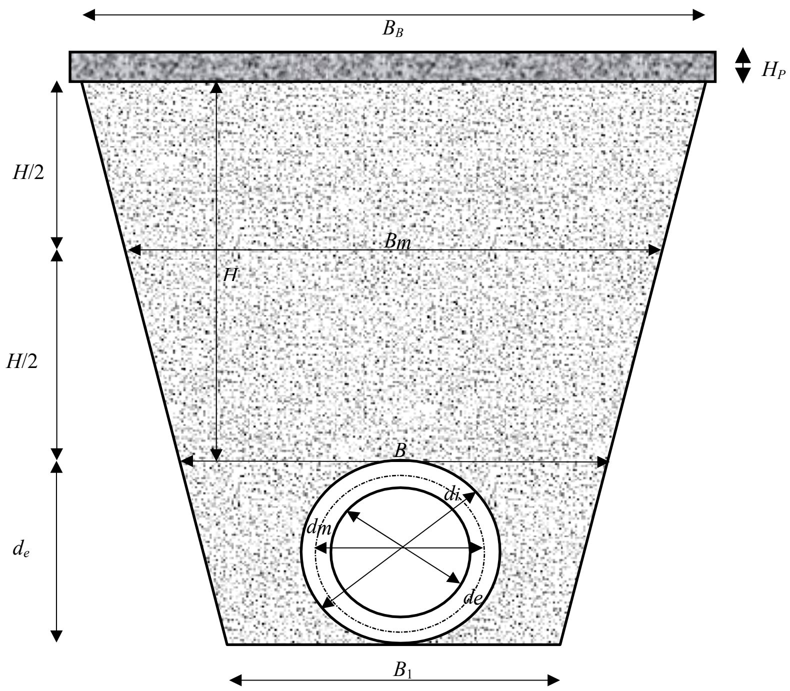


Figure 2. Arrangement of pipes in the trench

3. NUMERICAL MODELING OF THE STRESS STATE OF PIPE

To study the stress-strain state of the pipeline, the pipe was modeled on the computer program PLAXIS 2D (Figure 3) [4, 7]. For this, in addition to the pipe, the soil mass under the pipe was modeled in two layers, with a total thickness of 50 m. Modeling was carried out by the finite element method. The mechanical characteristics of both the fiber-reinforced concrete pipe structure and the soil under the pipe were taken into account: the elasticity modulus of the pipe material, Poisson's ratio, and the soil deformation modulus. Under the influence of a seismic load acting in a direction perpendicular to the longitudinal axis of the pipeline, horizontal (u_x) and vertical (u_y) displacements were determined. For a pipe with a diameter of 3.0 m, the horizontal movements are u_x=35 cm, and the vertical ones u_y=10 cm.

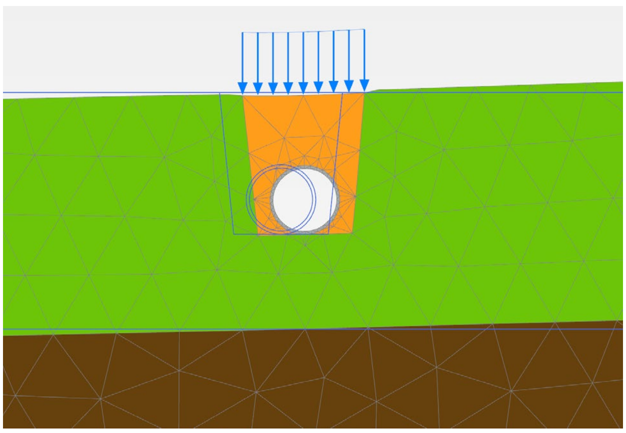


Figure 3. Design scheme of the soil massif around the pipeline modelled by means of PLAXIS 2D

The results of the maximum tensile and compressive stresses are as follows: for reinforced concrete pipes, the maximum tensile and compressive stresses are 20 MPa, for fiber-reinforced concrete pipes with metal fibers 17 MPa, for fiber-reinforced concrete pipes with polypropylene fibers 14 MPa. To determine the stress-strain state of the pipeline in the soil in a three-dimensional state, the modeling of the structure-soil system was carried out using the PLAXIS 3D and SAP2000 software. Finite element models were also used here (Figure 4).

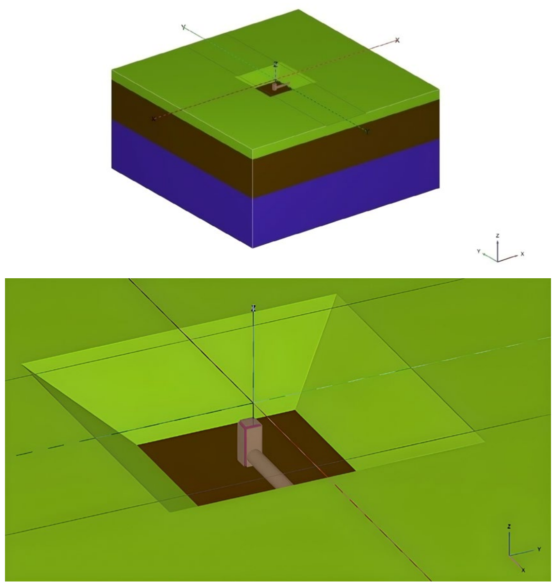


Figure 4. Plaxis 3D model of pipe with observation well

The soil in the ditch, surrounding soil and two masses of soil layers under it were taken as a feature in the following form:

Made ground: γ_{unsat}=1.8 t/m^3; γ_{sat}=2.0 t/m³; e= 0.6; k_f=3.0 m/day; c=0; E=1000 t/m^2; ν=0.4; R_{inter}=0.63.
Fine sand: γ_{unsat}=1.6 t/m^3; γ_{sat}=1.8 t/m³; e=0.65; k_f=1.0 m/day; φ=35°; c=0.1 t/m^2; E=3000 t/m^2; ν=0.3; R_{inter}=0.62.
Semi-hard clay: γ_{unsat}=1.95 t/m^3; γ_{sat}=1.95 t/m³; e=0.7; k_f=0.001 m/day; φ=20°; c=6.0 t/m^2; E=2400 t/m^2; ν=0.4; R_{inter}=0.48.

4. DESIGN OF THE CONNECTION POINT OF THE MOST DANGEROUS PART OF THE PIPE

According to international standards for the design of such pipes, the most dangerous element was the connection of the pipe with a manhole (Figure 9) [10]. The cross-sectional force (R_s) generated from this soil is perceived as the reaction force (F_s) in the pipe joint as the inverse and stabilizing force. Its calculation is calculated using the formula [10]:

$$R_s = \frac{F_s - \frac{W_w}{2}}{l_1 - a_s} \times l_1 \geq 0 \tag{8}$$

where, W_w is water weight inside, kN; a_s is the distance giving the moment for the point of union; l_l is a length of pipe. If we can calculate the earth load that falls into the connecting part of the pipe, R_s, then we can calculate the force of the critic reaction.

If we can calculate the earth load that falls into the connecting part of the pipe, R_s, then we can calculate the force of the sharp reaction [10]:

$$F_s = \frac{R_s(l_1 - a_s)}{l_1} + \frac{W_w}{2} \tag{9}$$

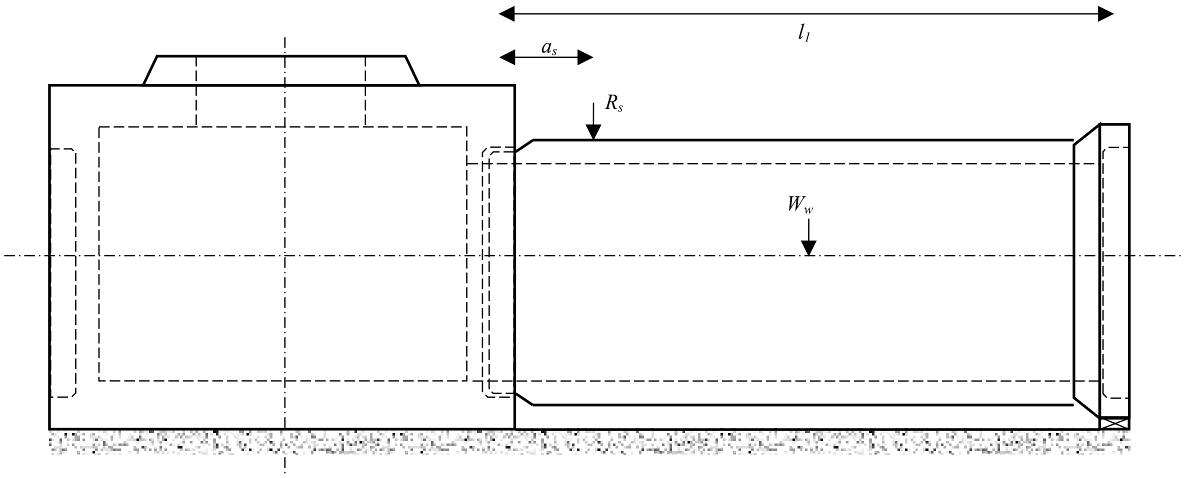


Figure 5. Soil pressure acting on the joint between the pipe and inspection pit [ASTM C 496/C 496M-04] [10]

The connection of the pipe to a common inspection well and the connection of one to one is shown as follows (Figure 6). Water sewer pipes were modeled according to the SAP2000 program and indicated as a design diagram of the pipe. One of the pipes was placed in the form of an embankment and was taken into account in a summer form, having a certain rigidity of connection with the soil in which it was sitting.

The calculation used 4272 quadrangular membranes with a finite element and 4438 points of the node. The calculation also takes into account the seismic load equal to the upper land load falling into the pipe, the road surface and the transport load moving along it. The stress is calculated separately for reinforced concrete, steel and polypropylene fiber concrete pipes (Figure 7).

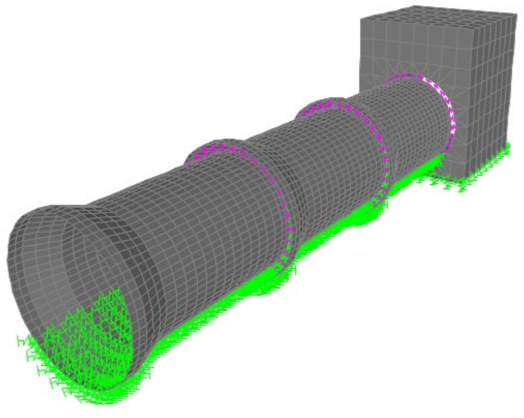
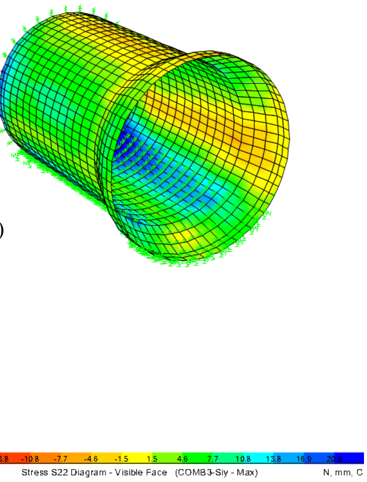


Figure 6. Pipeline modeling with SAP2000 program

(a)



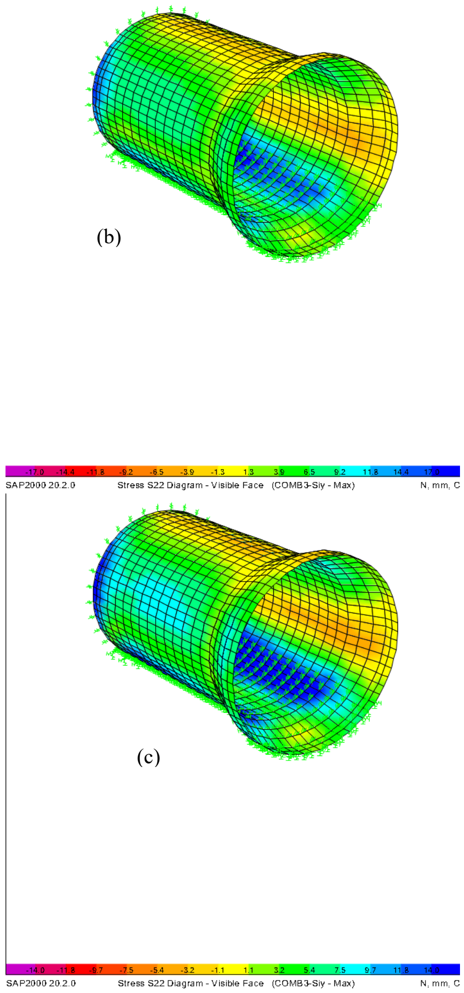


Figure 7. Main effective stresses taking into account the seismic load, (a) in a reinforced concrete pipe with a diameter of 1200 mm (seismic load + vertical force in the *Y* axis direction); (b) in the steel fiber concrete pipe (seismic load in the *Y* axis direction + vertical force); (c) in polypropylene fiber pipe

The same procedure is designed for diagrams reflecting the difference in seismic force in pipes. Arrangement of pipes formed in pipes from vertical ground load and seismic load is specified in Table 2.

Table 2. Pipe displacement values depending on the direction of load

N	Pipe type	Direction of the force of influence	Maximum displacement δ_{max}, mm	Minimum displacement δ_{max}, mm
1	Reinforced concrete pipeline	Vertical forces	13	6
2	Reinforced concrete pipeline	Seismic forces in the *Y* axis	75	35
3	Fiber concrete with steel fibers	Vertical forces	14	7
4	Fiber concrete with polypropylene fibers	Seismic forces in the *Y* axis	78	39
5	Fiber concrete with polypropylene fibers	Vertical forces	15	8
6	Fiber concrete with polypropylene fibers	Seismic forces in the *Y* axis	84	42

Structural recommendations for strengthening of the pipeline ground base are shown in Figure 8.

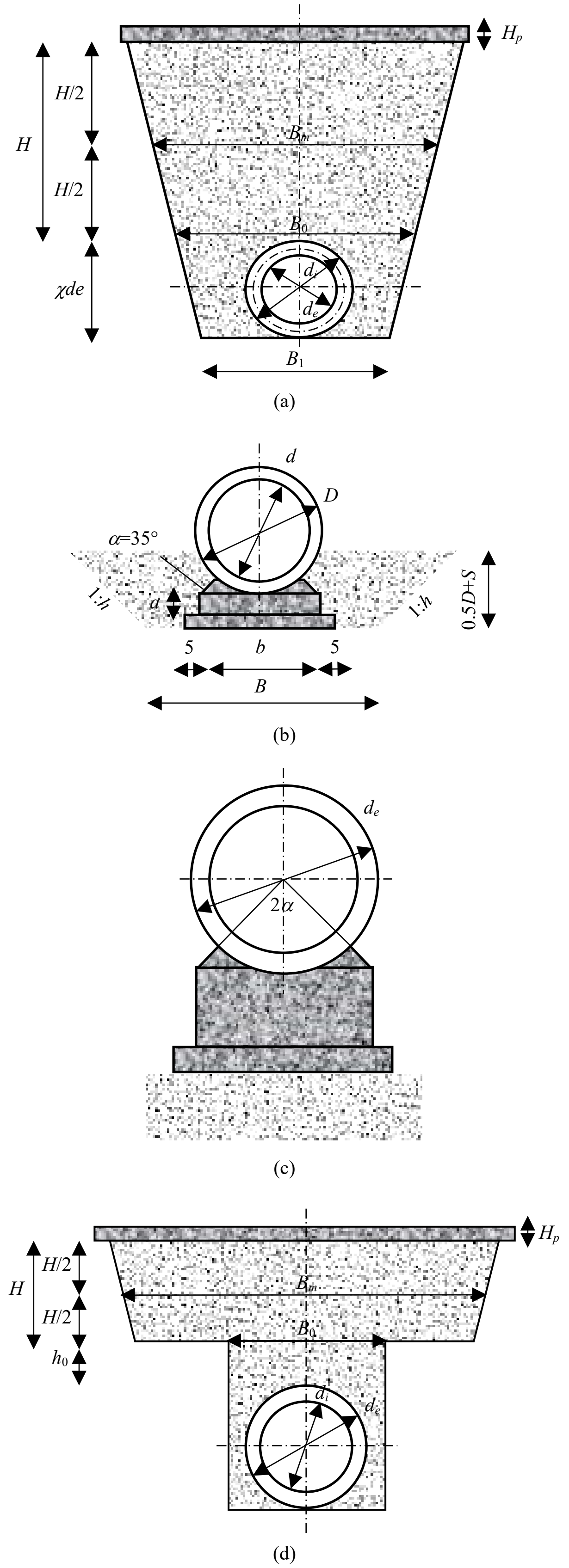


Figure 8. For pipes with a diameter of 600-3500 mm, a) in dry soils with a pressure of $P > 0.15$ Mpa in ditches up to 6 m deep; b) for pipes with a diameter of 800-2500 mm in dry and wet sandy soils with soft plastic $P < 0.15$ MPa; c) in cast soils under the same conditions; d) more than 6 m deep

5. CONCLUSIONS

1. For weak water saturated soils is necessary to strengthen the subsoil under the pipe regarding special retrofit project.
2. With increasing diameter and respectively the weight of the pipe, increases the horizontal and vertical displacement. In this respect, for pipelines of large diameters, structural measures are essential under the base of the pipeline.
3. To prevent the accident situations in the pipe joints, it is necessary to frame each connection with a special structure.
4. With an increase in the diameter of the pipe, the horizontal component of the seismic load perpendicular to the longitudinal axis of the pipe increases. This, in turn, contributes to the appearance of cracks in the pipe and the loss of strength of the pipeline as a whole. The production of pipes from fiber-reinforced concrete increases the crack resistance and strength of the pipe.
5. With an increase in the diameter of reinforced concrete pipes, their wall thickness of the pipe increases and, accordingly, the soil pressure. Double reinforcement is made and the diameter of the reinforcement increases. All this creates difficulties during concreting, cracks appear on the surface of the pipe. In addition, the preparation time of the pipes increases. The use of fiber-reinforced concrete significantly reduces the time of concreting.

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