International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

March 2023 | Issue 54 | Volume 15 | Number 1 | Pages 87-92

TECHNICAL RULES FOR DESIGN AND EXPERIMENTAL RESEARCH OF FIBER CONCRETE SEWER PIPES

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Abstract- This paper shows the structure of the Technical Rules for the design, calculation, testing and production technology of fiber concrete sewer pipes. The Technical Rules include information on the material of the pipe-concrete, various chemical additives and fibers (steel and polypropylene), test methods for composite material, methods for calculating the structure for a combination of loads, issues of production technology of fiber concrete pipes. This Technical Rules is accredited and state-registered by Azerbaijan Certification Institute and is a mandatory document for the design of fiber-concrete sewer pipes in the territory of Azerbaijan.

Keywords: Fiber Concrete, Sewer Pipes, Strength, Crack Resistance, Stiffness.

1. INTRODUCTION

This Technical Rules contains a methodology for calculating, designing, testing and manufacturing technology for fiber concrete sewer pipes. To drain atmospheric water, underground sewer pipes are usually laid at a depth of 6-8 m under roads and railways. The Technical Rules considering the climatic conditions of Azerbaijan, static and dynamic loads acting on the structure of fiber concrete pipes. The requirements of this Technical Rules must be strictly observed on the territory of Azerbaijan. This Technical Rules consists of 9 sections: terminology; technical requirements; calculation method; materials; physical and mechanical laboratory research; rules for labeling, acceptance, and storage; pipe testing; rules for the production and technology of fiber concrete pipes; instructions for use, 2 appendices and a list of literature of 26 items. The technical regulation also includes 16 figures and graphs, and 11 tables [1].

2. TECHNICAL REQUIREMENTS

Fiber concrete pipes are manufactured with an outer diameter of 600 mm; 1000 mm; 1200 mm and 1400 mm. The dimensions of fiber concrete pipes, their longitudinal and cross sections are shown in Figure 1 and Table 1 [1]. The connection of pipes is carried out by introducing one pipe into another through an expanded section. The connecting parts are fixed with rubber ring gaskets.

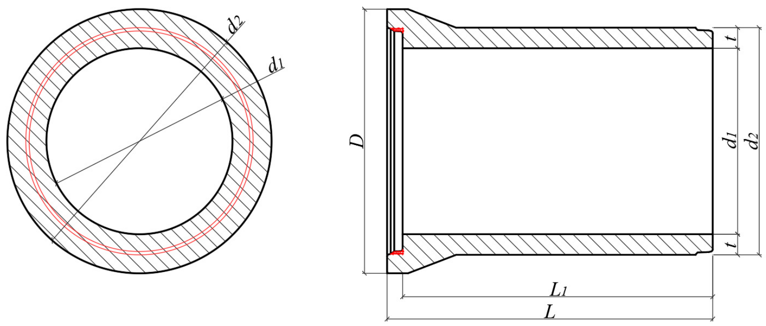

Figure 1. Longitudinal and transverse section of fiber concrete pipe [1]

Table 1. Classification of fiber-reinforced concrete pipes produced at the Evrascon enterprise [1]

No	Outer diameter of the pipe widening D, mm	Pipe outer diameter d_1, mm	Inner diameter of the pipe d_2, mm	Pipe wall thickness t, mm	Full pipe length L, mm	Main pipe length L_1, mm
1	1740	1400	1730	165	2125	2000
2	1704	1200	1466	133	2100	2000
3	1410	1000	1230	115	2100	2000
4	880	600	748	74	1590	1203

3. CALCULATION METHOD

The following normative documents were used in the calculation of underground sewer fiber concrete pipes: ASCE 27-00; ASTM C 1018-97; EN 14651 [3]. The paper [11] presents the results of experimental studies of the destruction of round cylindrical shells when loaded with axial tensile force, the lateral surface of which is damaged by random rectilinear cuts-cracks. The scheme of the action of external and internal loads on the pipe structure is shown in Figure 2.

Modeling was carried out in a two-dimensional plane using the Plaxis 2D computer program and in three-dimensional space using the Plaxis 3D and SAP2000 programs [7, 8]. These programs are based on the Finite element method. From the action of a seismic load perpendicular to the axis of the pipeline, the distributions of stresses and deformations in all three directions are determined (Figures 3 and 4).

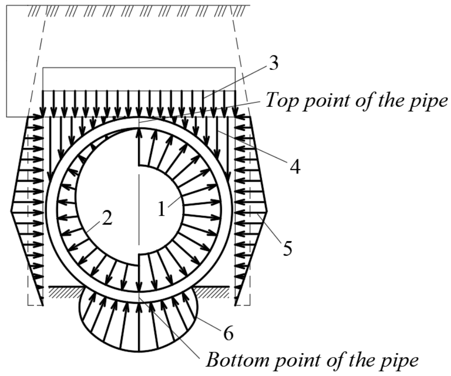

Figure 2. Forces acting on the pipeline, 1: Internal water pressure in the pipe, 2: The pipe's own weight, 3: The weight of the soil above the pipe, 4: The pressure of the bulk soil in the sinuses of the pipe, 5: Lateral pressure of the soil, 6: The reaction of the soil under the base of the pipe [2]

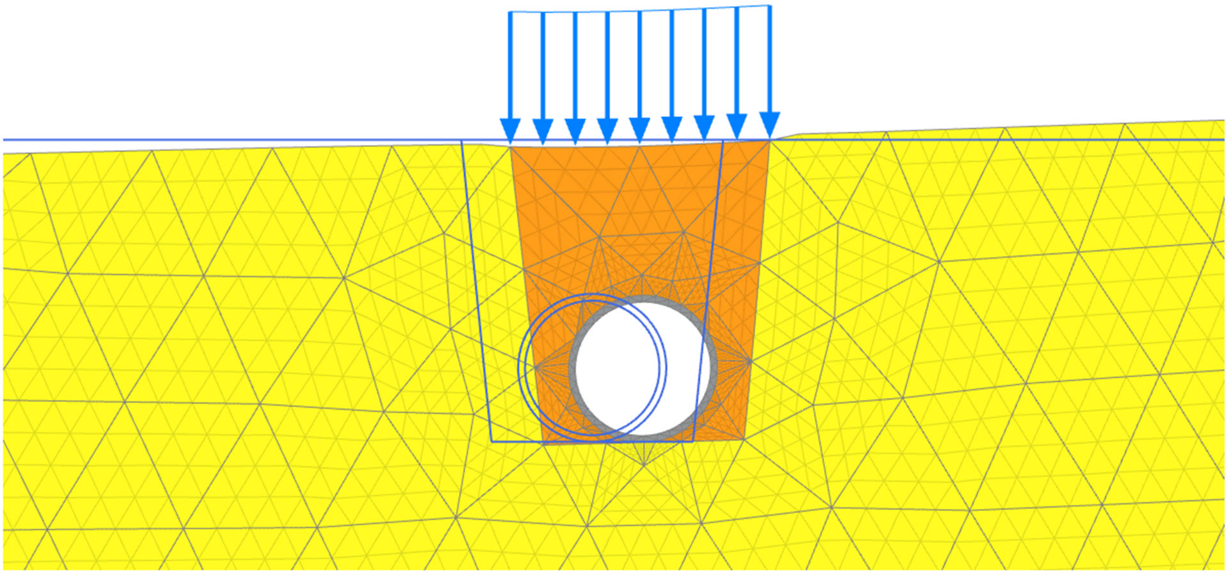

Figure 3. Deformation diagram of the simulated pipe-soil system in the Plaxis 2D program [1,7]

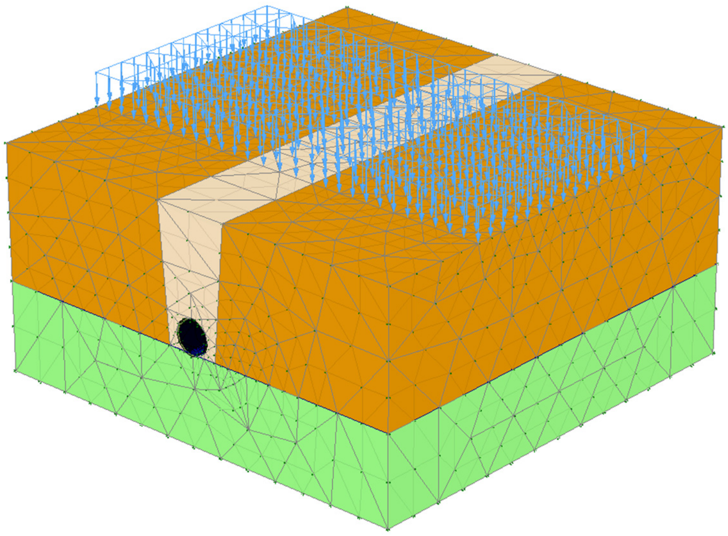

Figure 4. Modeling of the "pipe-ground" system on the Plaxis 3D computer program [1, 8]

The accelerogram of the earthquake in Kocaeli (Turkey) that occurred in 1999 was taken as seismic information. The magnitude of the earthquake was 8 points, the magnitude of the earthquake was 7, and the acceleration was 0.2 g. Compressive and tensile stresses in the pipe are given in Table 2.

Similar calculations were carried out to determine the deformation of the pipeline from seismic load. The results of calculations of pipeline deformation from seismic load along the *Y* axis and from the effect of vertical load from the soil are given in Table 3.

Table 2. Results of calculating stresses in fiber-reinforced concrete pipes

No	Pipe type	Maximum tensile stress σ+, MPa	Maximum compressive stress σ-, MPa
1	Reinforced-concrete pipe	20	20
2	Fiber concrete pipe with steel fiber	17	17
3	Fiber concrete pipe with polypropylene fiber	14	14

Table 3. The results of calculating displacements in fiber-reinforced concrete pipes from the action of vertical and horizontal seismic loads

No	Pipe type	Direction of active load	Maximum displacement δ_{max}, mm	Minimum displacement δ_{min}, mm
1	Reinforced concrete pipe	Vertical load	13	6
2	Reinforced concrete pipe	Seismic load along *Y* axis	75	35
3	Fiber concrete pipe with steel fiber	Vertical load	14	7
4	Fiber concrete pipe with steel fiber	Seismic load along *Y* axis	78	39
5	Fiber concrete pipe with polypropylene fiber	Vertical load	15	8
6	Fiber concrete pipe with polypropylene fiber	Seismic load along *Y* axis	84	42

The most dangerous place in the section of the pipe is the connection place. Therefore, in the International Standards, this load is separately calculated. The shear load (R_s) in the pipe connection is inversely proportional to the reaction load (F_s) and is l_1 is the length of the pipe. If the load incident on the connecting part R_s is known, then the reaction can be calculated taken as a stabilizing load and calculated by the formula [3].

$$R_s = \frac{(F_s - \frac{W_w}{2})}{(l_1 - a_s)} \times l_1 \geq 0 \tag{1}$$

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

where, W_w is the weight of the pipe with water content, kN; and a_s is the moment generating distance in the connection [3].

4. MATERIALS

The pipe material is a composite material and consists of concrete, chemical additives and steel or polypropylene fiber.

4.1. Concrete

Fiber concrete pipes are made of heavy concrete class C30/37. Cement is used brand Expert 42.5R, natural sand fraction 0-0.8 mm, crushed stone fraction 15-25 mm. The requirements for concrete are as follows:
- Water absorption of concrete should not exceed 6% of the total mass.
- The water resistance of the concrete must not be lower than W4.
- Frost resistance of concrete for the conditions of Azerbaijan should be F25.

4.2. Fiber

Below are the characteristics of the fiber-reinforced concrete mixture according to the required standards. The mobility of the fiber-reinforced concrete mixture is 0 - 12. Average density is not less than 2400 kg/m^3. Stratification of the mixture is 3%. The coefficient of fiber propagation K_p for steel fiber is 0.55. In the manufacture of fiber-reinforced concrete pipes, steel and polypropylene fibers are used, their cross section differs in mechanical characteristics. There are steel fibers of type 3D, 4D and 5D.

For polypropylene fiber, the setting of the fiber-reinforced concrete mixture is at least 45 minutes, maximum - 4.5 hours. To improve the technical characteristics of fiber-reinforced concrete, super- and hyper plasticizers can be used. In the manufacture of fiber-reinforced concrete pipes, plasticizers from BASF Master Cast 777 were used. This additive is 0.1-1.2% of the total mass of cement. The water needed to mix the mixture is added along with the additive. Therefore, each new type of fiber must be tested in the laboratory on a sample of fiber-reinforced concrete.

4.2.1. Steel Fibers

Steel fibers are made from steel wire or cut from steel sheet, each fiber, depending on Mr. Fix. These fibers have different mechanical characteristics and are listed in the table.

4.2.2. Polypropylene Fibers

Plastic polypropylene fibers are imported into the country by various chemical construction companies. Among them are the companies BASF, SIKA.

4.2.3. Percentage of Fiber

For fiber-concrete pipes the fiber composition is: for steel fiber 20-40 kg/m^3; for polypropylene fiber 4-6 kg/m^3. Depending on the size, type of fiber and class of concrete, this ratio may vary. The fiber concrete mixture is determined by the stratification coefficient [5].

Table 4. Indications of the mechanical characteristics of polypropylene fibers used in laboratory research [1]

No	Type of fiber	Length, cm	Section (d), mm	Tension strength, MPa	Modulus of elasticity, GPa
1	BASF 240	4	0.75	338	4.8
2	BASF 249	4.8	0.85	400	4.7
3	Mikrosintetik Sika PPM 12	1.2	0.18	-	-
4	SikaFiber T-48s	4.8	0.9	500	20
5	SikaFiber T-60s	6	0.9	500	20

$$K_p = \frac{P_u}{2P_{as}} \tag{3}$$

where, P_u is total fiber mass; P_0 is the fiber mass collected at the bottom of the sample. The coefficient of homogeneity of fibrational is determined by the expression [5]:

$$K_0 = \frac{m_{fr}}{m_f} = \frac{V \times \mu_f \times \rho}{100 m_f} \tag{4}$$

where, V is volume of fiber concrete mixture in a cube, cm^3; μ is the stratification coefficient according to the project; ρ is a fiber density, g/cm^3; m_{fr} and m_f are required and actual fiber mass.

5. TESTING OF FIBER CONCRETE PIPES

Tests of fiber-reinforced concrete pipes were carried out in the testing laboratory of the Institute of Building Materials. Pipes with steel and polypropylene fibers were tested for static compressive load. As a result of the tests, the modulus of elasticity, Poisson's ratio and other mechanical characteristics were determined. In addition, Separate tests of the fiber concrete material for bending, stretching, splitting were carried out. And also, testing for frost resistance, water resistance, resistance to abrasion and dynamic impact. The paper [11] presents the results of experimental studies of the destruction of round cylindrical shells when loaded with axial tensile force, the lateral surface of which is damaged by random rectilinear cuts-cracks. The results of the testing are shown in Table 5 [2].

Figure 5. Testing of the fiber concrete samples [2]

Figure 6. Testing of the fiber concrete pipe [2]

Table 5. Test results of fiber-reinforced concrete pipes with different fiber content

No	Type of the sample	Maximum load, kN	Maximum vertical compression deformation, mm	Maximum expansion deformation, mm
1	Fiber concrete pipe (20 kg/m^3 of steel fiber)	123.67	15	2.5
2	Fiber concrete pipe (30 kg/m^3 of steel fiber)	162.50	15	0.1
3	Fiber concrete pipe (40 kg/m^3 of steel fiber)	153.55	20	4

6. OPTIMIZATION OF PIPE REINFORCEMENT WITH FIBER

The results of testing pipes with various fiber additives showed that an increase in the fiber content in fiber concrete does not always improve the strength of pipes. The optimal fiber content in concrete was determined by the golden section method. The change in pipe strength from fiber content is taken as [1]:

$$f(x) = ax^2 + bx + c \tag{5}$$

Then the system of equations based on the results of pipe testing will have the form [1]

$$\left.\begin{aligned} a\times 20^2 + b\times 20 + c &= 123.67 \\ a\times 30^2 + b\times 30 + c &= 162.5 \\ a\times 40^2 + b\times 40 + c &= 153.55 \end{aligned}\right\} \tag{6}$$

Solving the system of equations gives us: a= -0.2389, b= 15.823 and c= -97.23. If the search interval is divided into two parts using the golden section method, then the optimal points x_1 and x_2 can be determined, Figure 7 [1]. Determine the optimal area through the system [1]:

$$\left.\begin{aligned} x_1 &= a + \frac{3-\sqrt{5}}{2}(c-a) \\ x_2 &= a + \frac{\sqrt{5}-1}{2}(c-a) \end{aligned}\right\} \tag{7}$$

If the maximum amount of additive is taken as c = 40 m^3 and the minimum a = 20 m^3, then x_2=32.36 and x_1=27.63. The optimal range of fiber composition in concrete (kg/m^3) was determined. Based on Table 5, a larger fiber content does not always lead to greater durability. Here, the optimal fiber range is between x_1 and x_2 is 27-32 km^3. That is, 30 kg/m^3 can be considered optimal for these pipes.

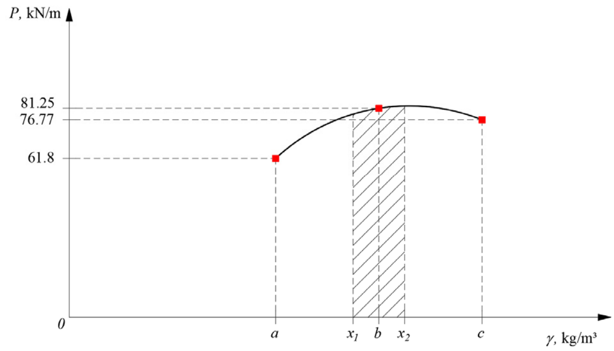

Figure 7. Testing of the fiber concrete pipe [1]

7. PRODUCTION TECHNOLOGY

Underground sewer fiber concrete pipes with a diameter of D 600, 1000, 1200 and 1400 mm are produced at the Evrascon ASC reinforced concrete plant using special equipment for dry vertical vibrocompression by Entar. The main requirement for the manufacture of pipes is the absence of cracks on the surface of the pipe. Steel and polypropylene fibers completely replace the metal reinforcing cage. This reduces the pipe manufacturing time from 45 to 15 minutes. The selected pulp is added to the concrete mixer. Depending on the size of the pipe, the class of concrete and the type of fiber, the required amount of fiber is determined.

From the mixer, the fiber enters the conveyor with dry concrete through the hopper, then it is poured from the conveyor into a mold. In case of sticking of the fiber into a ball, the conveyor operator eliminates the defect.

(a) (b) (c) (d)

Figure 8. Production of sewer fiber concrete pipes at the Evrascon ASC plant, (a) closing the lid of the mold of the vibro-pressing stand, (b)-(c) pipe stripping, (d) installation and transportation of the marked pipe [1]

8. CONCLUSIONS

The results of theoretical and experimental studies were included in the regional standard Technical Rules "Underground fiber-reinforced concrete non-pressure sewer pipes". This document has received state registration TS AZ No. 1000085511.002-2020 and has registration No. 1955 from the Azerbaijan Institute of Standards. A study of underground pipes of large diameter (more than 600 mm) for seismic load according to all international regulatory documents showed that to date no calculations have been carried out for the horizontal seismic component of seismic load.

For each class of concrete and type of fiber, laboratory tests were carried out and the physical and mechanical characteristics of the material were determined. Modulus of elasticity with polypropylene and steel fibers increased by 16-30%; tensile strength by 16-30%; Poisson's ratio by 5-20%. The economic efficiency of the production of fiber-reinforced concrete pipes has been calculated. Thus, the difference in the savings of metal, labor and working time for each pipe in terms of a monetary unit was approximately $60 US.

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