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NUMERICAL ANALYSIS OF THE EFFECT OF SEISMIC LOAD ON A FIBER-CONCRETE PIPELINE BY THE FINITE ELEMENT METHOD

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ABSTRACT. Fiber concrete sewer pipes in the seismic zones are presented. The pipes in the ground massive are modelling with the help of Plaxis 2D computers program. For the definition of the necessary mechanical characteristics were conducted experimental tests.

Keywords: fiber concrete, seismic load, stress, strength, tension

Introduction

Underground water sewer pipes are made of reinforced concrete. Length of such pipes changes from 1 to 2.5 m, diameter changes within 600-3000 mm. Pipes are established underground at a depth of 4-6 m and are connected among themselves by means of bell-shaped connection. At the production of reinforced concrete pipes there are following problems. The protective layer of concrete not always meets standards. On a surface of a pipe and in it there is a set of cracks, splitting off and other defects. All this increases pipe production time. Pipes are made at the concrete plant by the method of dry pressing. The internal and outer surfaces of pipes are leveled by masters manually. A feature of underground pipelines is that the soil massif is accepted not only as external loading but also as the environment. Therefore the design of the stress-strain condition of construction comes down to the design of the "underground pipeline-the soil environment" system. The durability of underground pipelines is rather investigated. However, the influence of seismic loading and the arising reactions of pipes remain not solved [1, 2]. The numerous cases of failures of underground pipelines from seismic influence show that axial tension is a result of accidents [3]. It takes place in case of welded metal pipelines more. Reinforced concrete pipes have a simple connection; an entrance part of a pipe does not exceed 10 cm. Therefore the cross and sedimentary deformations arising at seismic influence create a danger of detachment of pipes. The uneven draft is one of the causes of the accident. For pipes of large diameter cross loading at seismic impact has a great influence.

Replacement of a steel reinforcing framework in pipes with fibers considerably reduces the arising problems [5]. Full replacement of a steel reinforcing framework reduces welding works and volume of the spent electric power. The tension concrete resistance increases, longitudinal cracks and a splitting off are as a result reduced. Depending on the type, the size and volume of fibers laboratory tests on tension, a bend and crack resistance were conducted.

Now various normative documents do not consider cross components of seismic loading in calculations of underground pipes. At big magnitudes of the earthquake and for pipes of large diameter this approach is not correct. One of the reasons for accidents of pipes is the arising ring tension [7, 8] (Fig.1).

The arising tension is widespread unevenly and depends on a tilt angle of the influence changing from 0 to 2π. The normal tension stress at top of a pipe is $\sigma_M = \frac{0.305 P_m R^2}{W}$, at the edges of a pipe is $\sigma_M = \frac{0.1684 P_m R^2}{W}$. The normal compression stress at top of a pipe is $\sigma_N = -\frac{0.02653 P_m R}{F}$, at the

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a) *b)*

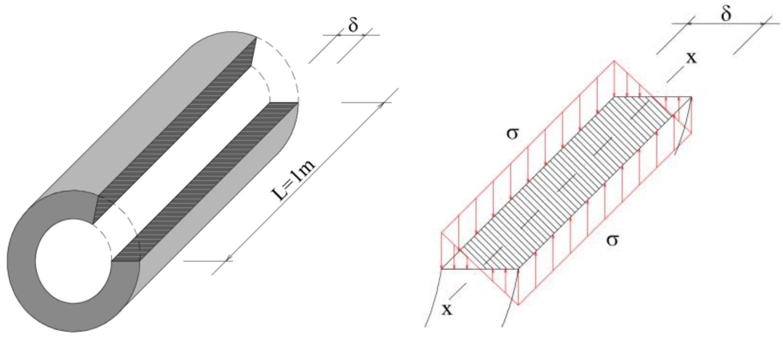


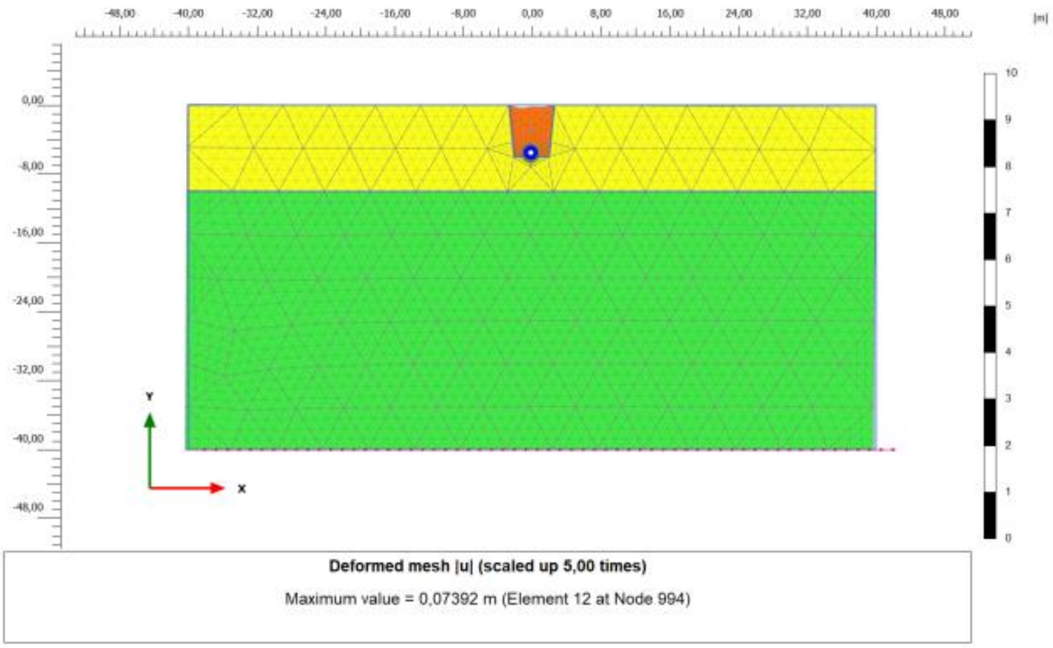
Figure 1. Cross-section of pipe *(a)* and normal stress diagram distribution *(b)*

edges of the pipe $\sigma_N = -\frac{0.5P_m R}{F}$. Here $W = \frac{d\delta^2}{6}$ is the pipe wall section strength moment; $F = \delta L$ are a pipe wall cross-sectional area. The maximum seismic compression and tension stress is calculated as $\sigma_i = \sigma_N + \sigma_M$. [8].

Modelling of the pipelines and ground massif

The underground pipeline and the soil massif surrounding it is accepted as a uniform object. The soil massif around the pipeline by means of the computer Plaxis 2D program is modelled according to the square and diagonal scheme on the rectangular site (Fig.2). Properties of this massif are characterized by two constants - the module of elasticity of soil (E_0) and the Poisson ratio (μ_0). Geometrical change of a system (the pipeline and the soil massif) is connected with the change of points of a grid. The cross contour of a pipe is also divided into final elements. Pipe material (fiber concrete) is characterized by the module of elasticity (E) and the Poisson ratio (μ). Such an approach to a solution of a problem of design a pile soil by means of the Plaxis 2D program was applied by the Holland engineers at the design of new Baku International trade port [9].

a)



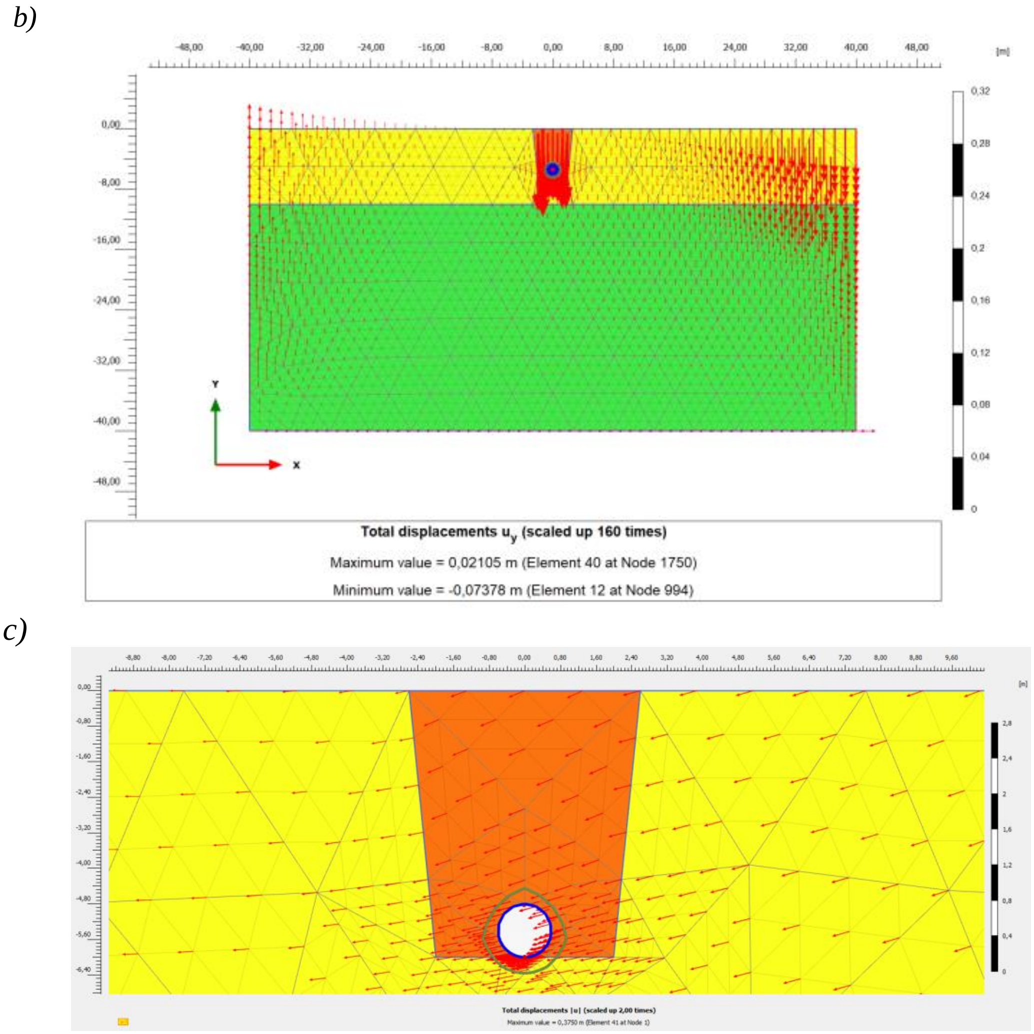


Figure 2. Plaxis 2D computer program for solution pipe-ground system modelling *(a)* and displacement on the Y- axis *(b);* General movements *(c)*

Here bulk soil is marked by orange color; clay is shown by yellow color; stony dense sandy loam is shown by green color. Movement of the lower part of a pipe on axis X makes U_x= - 0.1977 m. Movement of the lower part of a pipe on axis Y makes U_y= - 0.05077 m. The general movement of the lower part of a pipe makes |U|=0.2041 m. The pipe consists of 8 final elements. The quantity of elements of soil is 280 units. The average size of elements is 4.835 m. The maximum size of elements is 8.117 m. The minimum size of elements is 0.01006 m. The sequence of calculation following. At first parameters of the movement of knots are defined. Then deformations and efforts in cores from the movement of knots are specified. These values of efforts are transferred to knots. Displacements of knots are defined by the solution of a system of the equations of the movement of these knots. For seismic information of the territory the accelerogram of an earthquake was admitted to Kochaeli (Turkey) in 1999 (Fig.3). Calculations were carried out on earthquake action by the acceleration of 8 points by MSK 64 scale. Force of an earthquake is estimated measuring 7, acceleration is accepted 0.2g.

The modelled seismic loading is distributed on X and Y axes. From the action of seismic loading in walls of the pipeline there are compression and ring bend. In the perpendicular direction of

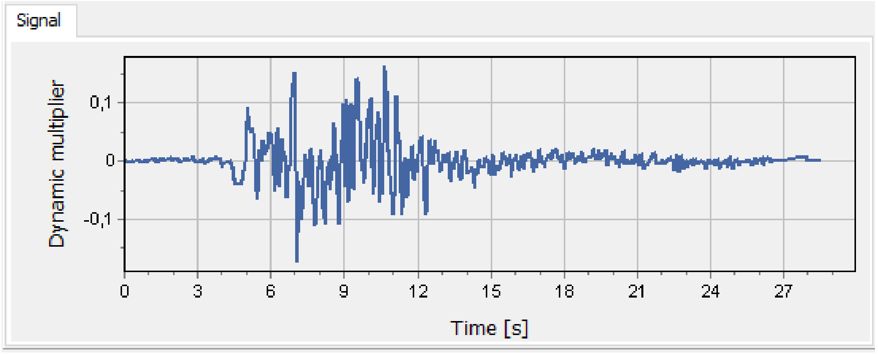


Figure 3. The accelerogram of an earthquake was admitted to Kochaeli (Turkey) in 1999.

an axis of the pipeline, the maximum tension of a bend and compression are calculated. The arising longitudinal forces *F(t)* and the bending moments *M(t)* from the action of seismic loading are calculated on formulas:

$$\left.\begin{aligned} F_k(t) &= \frac{EAv(t)}{\alpha_k V_k} \leq F_\tau(t) \\ M_k(t) &= \frac{EIa(t)}{(\beta_k V_k)^2} \end{aligned}\right\} \quad (1)$$

Where E is elasticity modulus of pipes materials (fiber concrete), Mpa; A is a pipe cross-section, m^2; $v(t)$ is a ground particles velocity speed, m/s ; V_k is a seismic wave velocity, m/s ; α_k , β_k are coefficients by wave type; k is a type of seismic wave (*1* is longitudinal wave, *2* is lateral wave); I is a moment of inertia of pipe, m^4 , $I = \frac{\delta^3}{12}$; δ is pipe wall thickness, m; $a(t)$ –seismic acceleration by accelerogram, m/s^2; $F_\tau(t) = \frac{\lambda_k f_\tau}{4}$ is a maximal cohesive force between pipe and ground; λ_k is a wavelength; T_0 is a seismic dominant period; $f_\tau(t)$ is a friction force. The velocity of a seismic wave $\mathbf{v_m}$ depends on the category of soil, $v_m = \frac{v_0 a(t)}{g}$. In this g is the acceleration of gravity. For soil of the first category is v_0=0,91m/s. For soil of the second category is v_0=1.2m/s. Deformations of diametrical expansion δ_x and shortening δ_y of a pipe can be defined as [4]:

$$\delta_x = \frac{0{,}1228\, P_m R^4}{E I_b} \quad , \quad \delta_y = \frac{0{,}122\, P_m R^4}{E\, I_b} \qquad (2)$$

where P_m is a seismic acceleration in the XY area;$I_b = \frac{\delta^3}{12}$ is a moment of inertia of the pipe. Various mechanical characteristics of soil depending on the type of soil are shown in table 1. Knowing a real geological section of the soil massif it is possible to determine actual speeds of a seismic wave. For bulk soil the speed of a seismic wave it is possible to accept 80 m/s .

Table 1

Soil type	Density of soil, ρ, kg/m³	Deformation moduls of ground, E_0, MPa	Poisson ratio of ground μ_0	Angle of internal friction of soil, φ, grad	Speed of distribution of a seismic wave in soil, v , m/s
Sand	2300	40	0,3	35	150
Sandy loam	1970	21	0,35	20	350
Loam	1700	35	0,42	57	600
Rock	2600	100	0,2	40	800

Test of fiber concrete samples and pipes

For the test of mechanical characteristics of fiber concrete pipes laboratory tests in the test hall of the research institute of building materials named after S. Dadashev were conducted [5]. Here tests on longitudinal tension (*a*), a bend (*b*), crack strength (*c*) and a splitting test (*d*) were carried out (Fig.4).

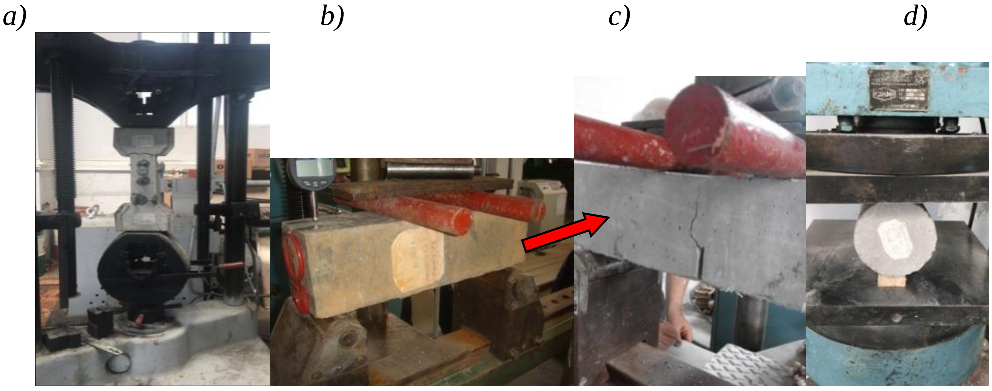


Figure 4. Fiber concrete tests: tension (a), bend (b), crack strength (c) and splitting test (d)

Here the steel and polypropilene fibers were tested. As a result of test the following indicators are received: for a steel fiber the module of elasticity E=60000 MPa, and Poisson ratio μ= 0,214; for polypropilene fiber the module of elasticity E= 25000 MPa, and Poisson ratio μ= 0,248. Tests of pipes were carried out according to the International Standards [1, 11, 12]. Pipes with a diameter of 600 mm and 1200 mm after production of 28 days contained in the territory of the plant for typesetting of durability. Together with reinforced concrete pipes, a pipe with steel and polypropylene fibers were prepared for the test. Tests were carried out at the testing laboratory of Institute of Building materials in Baku and at the concrete plant in Afgan TTS Consortium in Sheki (Fig.5).

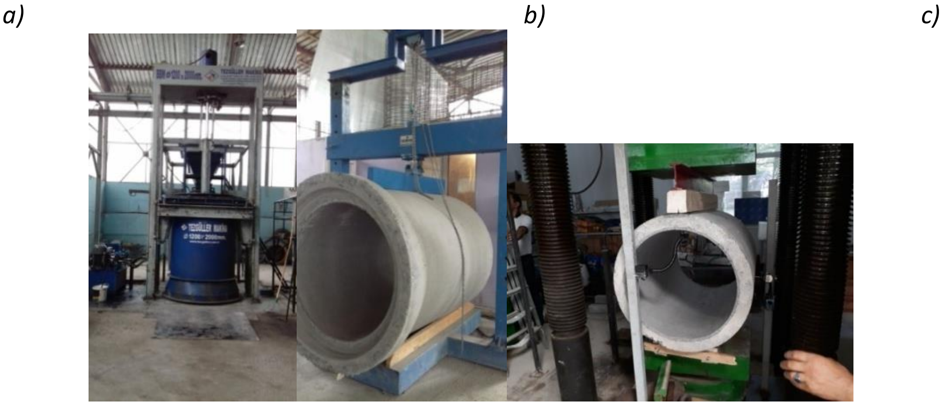


Figure 5. Production of the Ø1200mm diameters pipe in Sheki *(a)*; test of pipe *(b);* test of the Ø600mm diameters pipe in Baku (*c*).

Loading step by step on 400 kgf (4 kN) was transferred to a pipe. Each stage of loading kept 2-5 minutes for consideration and fixing of deformation and a crack in a pipe. Deformations were fixed by electronic sensors. Results of Ø1200mm and Ø600mm diameters pipe tests from class C30/37 are shown in Figure 6. It is possible to see that fiber concrete pipes without reinforcing framework show good results.

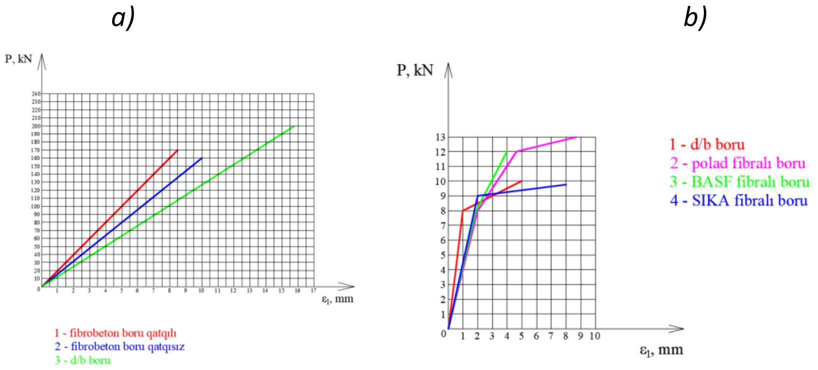


Figure 6. The *P-ε* stress-strain graphs of the tests from C30/37 class concrete of fiber concrete pipes: *a)* for Ø1200mm diameters pipes; *b)* for Ø600mm diameters pipes

Conclusion

As a result of researches the following conclusions are received:

1) The design model of the underground pipeline on seismic influence according to the Plaxis 2D program is developed;

2) With the increase in diameter of a pipe cross seismic loading increases. For example, for pipes with a diameter of 600 mm by 1.25 times and for pipes with a diameter of 1200 mm in 1.5 times in comparison with longitudinal seismic loading;

3) The tension of fiber concrete pipes from the action of seismic loading is 1.2-1.4 times less than in reinforced concrete pipes. It makes 10-15% of deformation of shift of a pipe. It is an indicator of high values of the module of elasticity and Poisson ratio for fiber concrete pipes.

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