THE REQUIREMENTS FOR CONCRETE LINING OF A SEWAGE COLLECTOR TUNNELS

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ABSTRACT. This article assesses the existing requirements for concrete lining of collectors, identifies weaknesses in each of the studied factors and presents the main directions for increasing the durability of structures. The main emphasis is made on the wear of the lining under the influence of filtration and aggressive media as the main reason for failure and destruction of such tunnels. The basic requirements for concrete lining of collector tunnels are: correct selection of dense waterproof concrete composition (i.e. method of calculation of waterproof concrete composition); choice of additives providing increased density, strength, and water resistance of concrete; investigation of some parameters of concrete mixtures compositions ensuring their resistance to abrasion; the choice of means and methods of protection of concrete lining against water-jet wear and corrosion of concrete caused by the aggressiveness of the media flowing through the tunnels.

Keywords: manifold tunnel, wear, concrete lining, fracture, corrosion

ИЗИСКВАНИЯ КЪМ БЕТОННАТА ОБЛИЦОВКА НА КАНАЛИЗАЦИОННИТЕ КОЛЕКТОРИ

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РЕЗЮМЕ. В статията се оценяват съществуващите изисквания за бетонна облицовка на колекторите, посочват се слабостите на всеки от изследваните фактори и се представят основните направления за повишаване на дълготрайността на конструкциите. Основният акцент се поставя върху износването на облицовката под влияние на филтрацията и агресивните среди като основна причина за повреди и разрушаване на такива тунели. Основните изисквания за бетонна облицовка на колекторни тунели са: правилен избор на плътен водоустойчив състав на бетона (т.е. метод за изчисляване на състава на водоустойчивия бетон); избор на добавки, осигуряващи по-голяма плътност, якост и водоустойчивост на бетона; изследване на някои параметри на състава на бетоновите смеси, осигуряващи тяхната устойчивост на износване; избор на средства и методи за защита на бетонната облицовка от износване от водни струи и корозия на бетона, причинени от агресивността на средата, преминаваща през тунелите.

Ключови думи: колектор, износване, бетонова облицовка, счупване, корозия

Introduction

The main requirements for the lining of sewer collector tunnels can be divided into the following:

- waterproofing properties;
- mechanical resistance;
- corrosion resistance;
- resistance to hydro-abrasive wear.

Currently, there is no information about the quantitative parameters of the above-mentioned requirements neither in the literature nor in the practice of underground urban construction. This leads to uncertainty in the creation of new means of protection of concrete lining from external factors and aggressiveness of media flowing through the collector tunnels.

Further research in terms of improving corrosion and water resistance, strength and wear resistance of the lining of the collector tunnels demands the assessment of the above-mentioned requirements.

Waterproofing properties of lining

Waterproofing properties of lining of sewer collector tunnels should ensure their sufficient water resistance, including by stopping the capillary movement of moisture in the pores of concrete.

Considering the water resistance of the concrete lining, it should be noted that the transfer of moisture in the concrete can be viscous or capillary flows, as well as due to diffusion transfer. In the first two cases, the transfer of the liquid itself with all the substances dissolved in it is carried out. The movement of the liquid through the pores and capillaries caused by its evaporation is determined by the expression:

$$i = X_{\Psi} \cdot \Delta\psi, \quad (1)$$

where X_{ψ} is the coefficient of liquid capillary conductivity;

$$X_{\Psi} = \frac{\gamma_g}{8\mu}\int_{r_0}^{2r_x} r^2 f\delta(r)dr, \quad (2)$$

$$\Delta\psi = \frac{\delta}{\gamma_g} \leq \left(\frac{1}{r_1} - \frac{1}{r_2}\right), \quad (3)$$

where γ_g – specific gravity of liquid; μ – liquid viscosity; $r_{1,2}$ – radius of curvature of meniscus.

A number of authors theoretically and experimentally proved that all three types of transport occur at the following filtration coefficients of materials (table 1). Thus, only K_f = $(3\div4)\cdot10^{-7}$ sm/h can ensure necessary and sufficient quantitative level of waterproofing protection of the collector tunnel.

Table 1. *Types of liquid transport*

Fluid transfer mechanism	Coefficient of filtration K_f, sm/h
Molecular diffusion	$3.48\cdot10^{-7}$
Capillary flow	$3.48\cdot10^{-7}\div3.48\cdot10^{-5}$
Viscous flow	$3.48\cdot10^{-5}\div3.48\cdot10^{-4}$784

The strength of the concrete lining of sewer tunnels.

The load-bearing capacity of the lining of the collector tunnels is to a certain extent determined by the strength of the material. Since the working conditions of the construction of the collector tunnel lining vary depending on the dynamics of the rock pressure and the nature of the interaction of the rock mass with the support, the strength properties of the lining material should be changed accordingly. In this regard, each material should be considered in terms of its ultimate strength.

Fig. 1 shows the dependence of some indicators characterizing the strength of the collector tunnel lining on the structural parameters of the bearing elements.

As the practice of underground urban construction shows, in the construction of the lining of sewer collector tunnels the most widespread concrete class is “B 40”, depending on the geological conditions.

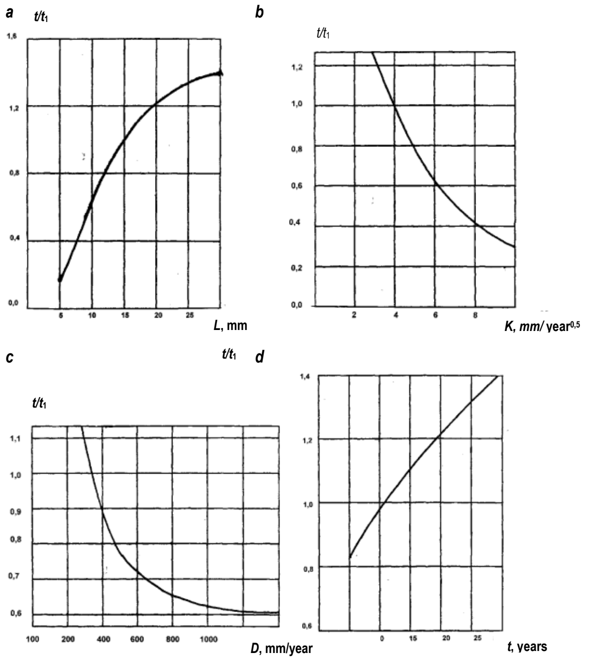

Fig. 1. The dependence of the time of the beginning of cracking (t/t_1) in the construction of the tunnel: *a* – on the thickness of the protective layer of concrete *L*; *b* – on the coefficient of carbonation *k*; *c* – on the diffusion coefficient of ions Cl; *d* – on the time of failure of waterproofing *t; t* – the average time of the beginning of cracking, years; t_1 - the time corresponding to the beginning of the decline in the reliability of the collector lining, t_1 = 18.3 years

An examination of the state of sewer collector tunnels lining in Moscow showed that in some cases the concrete lining of collectors does not satisfy the specified strength. Therefore, to ensure the necessary strength of concrete, it is necessary to overestimate its projected strength by 1.2-1.4 times, and in complex hydrogeological conditions even more.

Corrosion resistance of collector tunnels concrete lining

Statistics of failures of engineering equipment of cities shows that the frequency of accidents of sewer networks is increasing every year. There are frequent accidents, causing significant material damage associated with the failure of roads, the collapse of buildings, structures, and sometimes the death of people. Often failures of sewage facilities are accompanied by contamination of the soil and groundwater contained in the construction, discharge of domestic sewage into water bodies. Therefore, the fight against violations (failures) of sewer networks is relevant.

One of the aspects of failure control is the task of timely detection of corrosion damage of reinforced concrete structures of collectors.

Direct inspection of concrete structural elements of wells and concrete pipes, the measurement of strength parameters and rate of destruction of reinforced concrete elements under the influence of aggressive gas environment, gives the opportunity to prevent the deterioration of structures, to define the terms of their service and to carry out repair and construction works in proper time.

The corrosion resistance of the lining material has the greatest impact on the durability of the collector tunnels’ lining. The calculation of the effect of corrosion weakening of concrete on the bearing capacity of the collector tunnel‘s lining shows that the loss of the bearing capacity of the lining occurs when the strength of concrete is reduced 2 times compared to the design (under appropriate mining and geological conditions). The thinness of the concrete mostly contributes to the development of the corrosion processes of concrete.

The results of the quantitative assessment of the degree of corrosion resistance of metal and reinforced concrete structures are shown in table 2.

Table 2. *The degree of corrosion*

The degree of aggressive influence of the environment	Metal construction		Reinforced concrete structure	
	Uniform corrosion rate, mm/year	Average annual loss of bearing capacity during operation, %	Average annual loss of bearing capacity during operation in %	
			Underground construction	Bearing and enclosing structures
Poor	Up to 0.1	5	3	5
Middle	0.1 – 0.5	10	5	10
Strong	More than 0.5	15	8	15

It is assumed, that the structure is subject to major repairs or replacement with a loss of bearing capacity of 40-60 %.

The presence of additives in the concrete affects the degree of corrosion resistance of the reinforcement cage (table 3).

Table 3. *Corrosion rate of steel in concrete in humid atmosphere*

Concrete	Mass loss, g/m^2 per year	The maximum depth of corrosion of ulcers for the year, mm
Normal, no additives: • dense • porous	 0 13-210	 0 0.48
With chloride additives	10-660	1.63
Carbonated	30	-

The degree of corrosion of the reinforcement depends on the presence and magnitude of crack opening *K* in the body of the concrete lining of the underground structure, which clearly demonstrates Fig. 2 and formula (4):

$$K = \frac{10L^3\delta}{\frac{L/d + 1}{d^4}}, \qquad (4)$$

where *L* – the thickness of the protective layer of concrete, m; *d* – diameter of reinforcement, m; δ – crack opening, m.

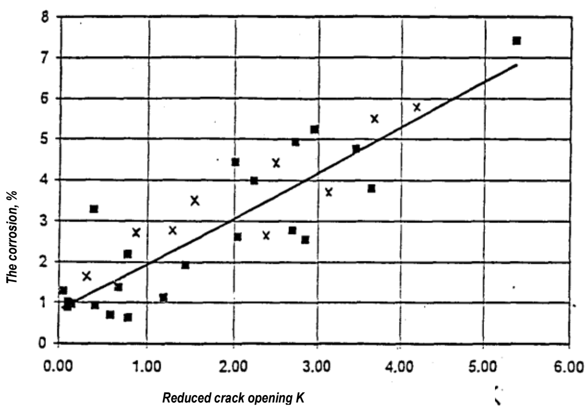

Fig. 2. Dependence of the degree of corrosion of the lining on the reduced crack opening in concrete

The value of corrosion of the reinforcement is a boundary condition for the transition of the structures of an underground building from one technical condition to another. Thus, at the corrosion value *K*(*t*) = 2% there is a transition of structures from I[st] to II[nd] category of technical condition, at *K*(*t*) = 7% – from II[nd] to III[rd] category, *K*(*t*) = 15% – from III[rd] to IV[th] category, *K*(*t*) = 25% – from IV[th] to V[th] category.

Corrosion of concrete also causes filtration of soft water through the lining of the tunnel. Leaching of 25% CaO from cement leads to a sharp drop in strength and to the complete decomposition of concrete in the future. If we assume that the average consumption of cement per 1 m^3 of concrete is 350 kg and that an average of 1 m^3 of concrete accounts for 210 kg of CaO, we can conclude: leaching 52.5 kg of CaO per 1 m^3 of concrete lining of the collector tunnel can lead to its destruction.

Studies have found that the process of decomposition of organic compounds in wastewater leads to the appearance of carbon dioxide, ammonia, hydrogen sulfide, methane and other gases in the surface part of gravity reservoirs.

In aerobic decomposition processes (involving oxygen), carbon dioxide is mainly released, and in anaerobic (oxygen-free) processes, hydrogen sulfide and methane are the main decomposition products, with the largest percentage being hydrogen sulfide. The appearance of hydrogen sulfide in the atmosphere of the surface part of the collector is accompanied by the development of thionic bacteria on its walls, under the action of which hydrogen sulfide is oxidised to sulfuric acid and acts as an acid condensate on the arch of the collector.

Chemical analysis of concrete corrosion products shows that they consist mainly of gypsum, silica, aluminum hydroxides and iron compounds. In the water-saturated state, corrosion products have a consistency of liquid dough and easily fall off from the ceiling and vertical surfaces.

The corrosion rate of concrete depends on the concentration of hydrogen sulfide and sometimes reaches up to 20 mm per year. This leads to the fact that such sections of the collector fall off after 5-10 years of operation.

In addition to the leaching aggression, aggression of flowing wastewater also acts on the concrete lining. As a result of the action of the gas condensate and microorganisms, which develop well in the mucous film covering the channel walls, on the concrete lining of sewage, there is a significant decrease in the content of CaO in concrete from 60-64% to 12% and an increase in sulphates from 1.5% to 42%. On average, the corrosion depth of concrete lining of collector tunnels is estimated at 6-13 mm per year.

Therefore, it can be assumed that the service life of the concrete lining according to the corrosion resistance factor varies between 20 to 35 years. However, it is known that the corrosion of concrete can have an avalanche character, which probably could lead to rapid destruction of the lining.

Currently, it is possible to control the characteristics of concrete (to increase its density and reduce porosity) by introducing additives (super-plasticizers to reduce the water-cement ratio, micro-silicates) or covering the concrete surface with materials that promote pore colmatation (Xypex, Squid, Penetron, etc.). This helps to increase the water resistance of concrete tunnel lining, its resistance to aggressive influences. However, this is not enough to prevent the destruction of concrete when exposed to an aggressive environment.

Protection of concrete lining from corrosion damage can be carried out in two directions: either increasing the density of concrete, or protecting the concrete with anti-corrosion coatings.

Conclusion

The abrasion of the concrete lining is determined by the amount of loss of the initial weight related to the surface of the abrasion area. Due to the impact of abrasive materials in the wastewater at speeds of more than 2 m/s there is an intensive abrasion of the tunnel tray.

As shown by estimations of the influence of the hydro-abrasive wear the tray part of the concrete lining on the bearing capacity of the collector tunnel's lining, when the abrasion is 40-60% of the thickness of the trough part of the tunnel lining, it loses its bearing capacity. On the basis of statistical data processing it was found that an average of 1.2 cm of the tray is worn out yearly. Consequently, the period of possible operation of the collector tunnel according to the factor of abrasion is within the range of 10-12 years.

Water-abrasive wear of the collector tunnel's lining begins with the washing out of the cement stone and the separation of grains of large and small aggregate, as a result the lining of the tunnel becomes rougher, and this in turn exacerbates wear.

Having considered the basic requirements for concrete lining of collector tunnels, we can assume that the main direction for increasing the durability of concrete lining sewer tunnels is:

- correct selection of dense waterproof concrete composition (i.e. method of calculation of waterproof concrete composition);
- choice of additives providing increased density, strength, and water resistance of concrete;
- investigation of some parameters of concrete mixtures' compositions ensuring their resistance to abrasion;
- the choice of means and methods of protection of concrete lining against water-jet wear and corrosion of concrete caused by the aggressiveness of the media flowing through the tunnels.

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