

Defects of urban underground structure and their prediction

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Abstract. The data for sub-terrestrial transport facilities and tunnel engineering systems, which have been used for a long time in a significant number of cities, can serve as a necessary material for the analysis of the state of lining of urban underground structures. The most important task in the field of design and construction of urban underground structures is to address the issue of durability of their lining, which provides for the reliability of the construction during a given period of operation at a minimum cost of its construction. The quality of construction, the service life of underground facilities and the capital costs required for its construction depend on the type of lining and the technology of its construction. Despite the high requirements for the design and production of works in underground construction, the supporting structures of underground facilities have a number of significant defects that lead to the failure of facilities and expensive repairs in a short time. The opening of the mechanism of formation of defects in the lining allows one to develop measures to prevent their formation, reduce the cost of operation and construction of underground facilities in the city.

1. Introduction

At present, it is almost impossible to obtain data on the state of the lining of the entire range of urban underground structures. Nevertheless, the data for sub-terrestrial transport facilities and tunnel engineering systems, which have been used for a long time and in a significant number of cities, can serve as a necessary material for the analysis of the state of lining of urban underground structures. Therefore, in this study materials of technical inspections of public and transport tunnels of the Moscow metro is used for the analysis of defects of lining of underground structures.

2. The nature of water filtration in underground tunnels

The nature and intensity of water filtration in underground tunnels is directly dependent on the hydrostatic pressure of groundwater [1-14]. According to the intensity, water filtration can be divided into three types:

- concentrated leaks, i.e. places where water flow is visible,
- dripping;
- dampness.

Concentrated leaks in deep tunnels are mainly observed in the areas with the most defective insulation and protective reinforced concrete shirt in the presence of significant through seams or cracks in the shirt and, probably, in the lining of the tunnel, as well as in the presence of gaps between the shirt and lining.



In shallow tunnels, concentrated leaks are observed mainly in temperature-sedimentary seams. The reason for this is the insufficiently thought-out design of insulation of temperature and sedimentary seams.

The design of the seam insulation is as follows: on the outside the seam is covered with a roll insulation material without the device of the fold (compensator) necessary for perceived deformation; on the inside of the seam insulation has a prism, filled with bitumen and caulked tow. From the first days of operation, bitumen squeezes out a tow from the seam and starts to flow out of a seam. This creates conditions for the free penetration of water through the seam. Adhesive insulation due to thermal deformation is likely break or upset at the joints and behind the lining.

According to the measurements, water flow rate (flow rate) filtered in some defective places and deep tunnels, is up to 200 l/min.

Dripping is a water filtration in the form of drops, which in most cases observed over large areas. In some places, such filtering is concentrated on areas of about 8-12 m² and in most cases is confined to the upper part of the tunnel – its arch.

This type of filtration is usually manifested in places where there are small gaps between the concrete shirt and the lining of the tunnel and loose (porous) concrete of the shirt, but without the presence of through cracks in it. The drop appears in places where the waterproofing is broken, and the lining has a porosity, in which there is a filtration of a small amount of water.

The dampness refers to the filtration of water, causing wetting of the concrete and the formation of a separate raw spots on its surface.

Some manifestations of filtration are seasonal, and water filtration occurs in spring and autumn. Such phenomena are observed only in shallow tunnels and indicate the dependence of the filtration of precipitation seeping into the soil and saturating it with water.

The largest number of water filtration sites in deep tunnels is concentrated on the sides of the tunnel, in shallow tunnels – almost at the level of the tunnel tray and at the overlap.

Places of filtration, as it is seen in Figure 1, located near the junction of the insulation and the seam of concreting and probably come from the looseness of the seam and junction isolation.

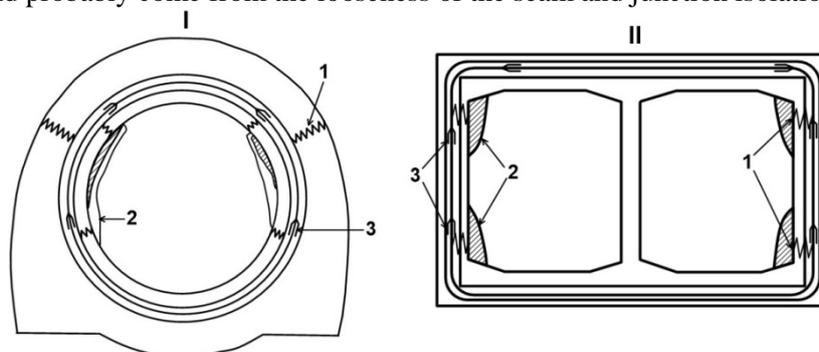


Figure 1. The layout of the filtration places (in the cross section): I – the cross section of the deep tunnel; II – the cross section of the shallow tunnel; 1 – seam; 2 – leak places; 3 - insulation joint.

In some cases, at filtration at stations decreases spontaneously and disappears after a while. Often after the disappearance of the filter in one place, it appears in the neighborhood, near. This phenomenon can be explained by the local self-compaction of concrete. One of the reasons for the self-compaction of concrete can be the blockage of pores in it with impurities that are contained in the ground water. Also, self-compaction can be caused by chemical processes in the concrete under the influence of chemical agents contained in ground water.

When the content of free carbon dioxide in the water can be the transformation of free calcium oxide hydrate into calcium carbonate. Calcium and magnesium bicarbonates contained in water can also react with calcium oxide hydrate.

The resulting particles of calcium and magnesium carbonate are deposited on the walls of the pores and gradually reducing their cross-section, swabbing the pores in the concrete.

The effect of filtering water on the concrete lining is most unfavorable when filtering in the form of a dripping. This type of filter covers, as mentioned above, the large surface and even with non-aggressive water may lead to corrosion of concrete-shirts in connection with the leaching of lime from concrete.

Concentrated large leaks can not cause much harm to the lining, as they wash a small surface of concrete, usually a small width of cracks – 2-3 mm. Even with aggressive water, concentrated leaks are less harmful to concrete than when the dripping of non-aggressive water covering a large surface. In such places primarily should be carried out work on the elimination of water filtration.

In tunnels, as a rule, in places with concentrated leaks, there is a deposition of red-brown, and sometimes white sinter formations, carried out by water. The drips are mostly located on the walls or in the tunnel tray.

White drips are deposited in the form of a dense shapeless mass or in the form of stalactites when filtering water through the reduced overlap and consist mainly (up to 65 %) of calcium carbonate. In most cases, drips are white when the host rocks around tunnel are limestone. Their origin can be explained by the fact that the water has a strong natural carbonation, and, in addition, there is a partial leaching of lime cement mortar due to the lining and to a lesser extent-the leaching of concrete lining.

Red-brown sinters have the form of silt scurf, sometimes foamy and mainly consist of hydrate of iron oxide (up to 22 %) and are a product of removal of ground water.

The assumption that there is a rusting of the reinforcement of the shirt, whereby water is saturated with iron, not thoroughly, since the leak, having a concentrated output, i.e. passing through a crack in the shirt of a few millimeters wide, can not give such a large amount of iron removal, which is available in some leaks.

Inspection of reinforced concrete shirt in places where there are red-brown scurf, found out very slight rusting of the reinforcement free of concrete, besides, the reinforcement itself is covered with a dense film of the same scurf. After 8 years of being in such conditions, the reinforcement has on its surface minor corrosion manifestations (in the form of separate depressions).

3. Durability of lining of underground structures

The most important task in the field of design and construction of urban underground structures is to address the issue of durability of their lining, which provides for failure-free operation of the facility for a given period of operation at a minimum cost of its construction. This items were investigated by many scientists [11-20].

The reliability of lining of underground structures changes during operation according to the following dependence (Figure 2) [2]:

$$\beta(t) = \beta(0) \left[1 - \frac{t^3}{\tau_0^3} \right], \quad (1)$$

where β – reliability index; τ_0 is the time corresponding to a decline of reliability; t – time of operation of underground structures, years.

The quality of construction, service life of underground facilities and capital costs required for its construction depend on the type of lining and technology of its construction.

Studies show that for example, the failure of the lining of sewer pipes or its partial destruction occurs under the influence of the following factors:

- hydro-abrasive wear of the chute of the tunnel;
- gas and chemical corrosion caused by the aggressiveness of media flowing through the tunnels;
- biological corrosion;

leaching of free lime from concrete under the influence of external groundwater.

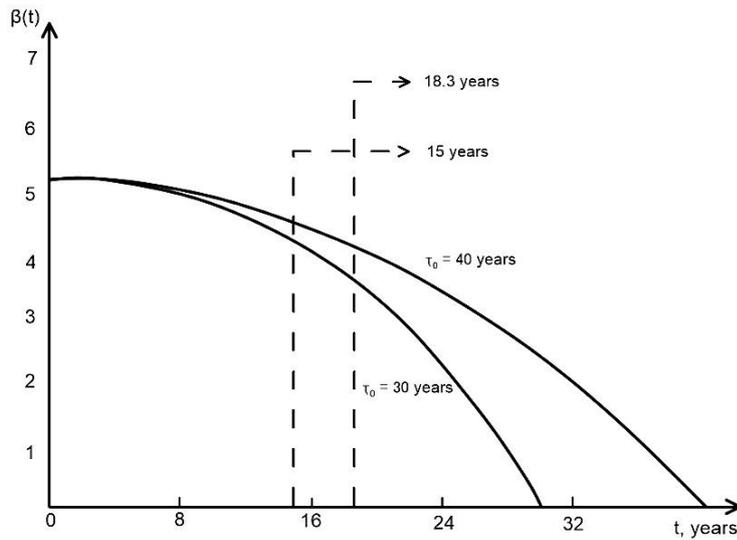


Figure 2. Changes in reliability from the time of operation of the underground facilities.

Each of these factors individually or combined action of several of them leads the lining toward an emergency condition or brings it down for a long time. The time dependence of the growth of defects in the supporting structures of the Moscow collector tunnels is shown in Figure 3 [4].

Estimates indicate a significant impact of corrosion and hydroabrasive wear of the tray of the tunnel on the bearing capacity of the lining of the collector.

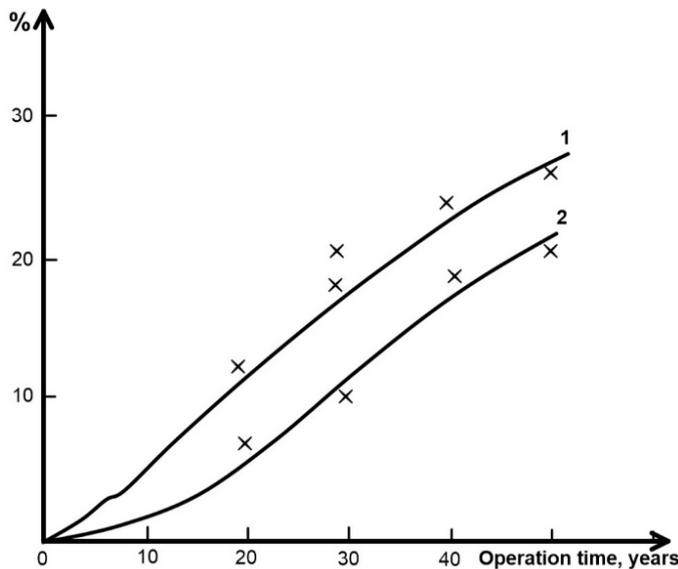


Figure 3. Growth of defects in structures of collector tunnels from the time of operation.

4. Types of lining defects

We received an idea about the status of more 19751 m of underground tunnels in a single-track basis, and 56142 m of collector tunnels. Some results and features of this examination are presented in table. 1, 2, from which it follows that all defects of the supporting structures of the surveyed underground structures can be divided into several types.

1. Cracks longitudinal, transverse, oblique-diagonal direction (relative to the axis of the structure).

For collector tunnels the most characteristic is the location of longitudinal cracks in the arch section, while in subway tunnels they are mainly confined to the place of interface of track concrete and blocks of the lining rings, the ends of the sleepers, the corners of the drainage tray, places of junction of structures. The length of cracks can reach several meters, their opening - up to 6-7 mm.

Transverse cracks in the collector tunnels are confined to the technological seams of the secondary lining, which is typical for most underground structures. At the same time the crack opening reaches 3 cm or more.

The formation of cracks, oriented both in the longitudinal and transverse direction, is facilitated by the corrosion weakening of the concrete lining. Longitudinal cracks are formed under the influence of external mountain pressure and internal hydrostatic pressure acting permanently or briefly. In the formation of transverse cracks, the main role is obviously played by uneven subsidence of soils under the tunnel and causing the appearance of bending moments. The formation of cracks increases the water permeability of the lining of the underground structure and can lead to the outpouring of sewage water on the aquifer, which is unacceptable from the point of view of sanitary norms.

In transport tunnels, these cracks are located at the base of the drainage tray, at the interface of adjacent excavations and underground structures, in the track concrete at the level of the ends of the sleepers and in the plane of the joint of wall concrete. Transverse cracks have a limited length and opening up to 7 mm.

Oblique-diagonal cracks are confined to the backs and ribs of concrete blocks and cast iron tubing and are the result of inconsistencies in the strength of the material of the lining by pressure developed by the jacks of the tunneling shield. Similar origin often have separate chips joints, corners and other similar defects.

2. Leaks, among which are dominated by “fistulas”, which are through holes, the diameter of which varies from 0.5 to 5 cm. “Fistulas” have a significant impact on the violation of the waterproofing properties of the lining of the underground structure and are active conductors in its water-sand mixture. Thus, when operating municipal underground facilities through “fistulas”, on average, up to 5-10 kg of sand per 1 m of tunnel is washed per month, which leads to the formation of large cavities behind the lining, the value of which can reach more than 3-7 m³.

“Fistulas” have a significant impact on reducing the filtration reliability of the lining of sewer tunnels. In general, without creating an emergency situation, they are the cause of leakage of fecal masses into the surrounding massif and, on the other hand, a conductor of sand, which is a powerful abrasion agent, into the tunnel. The most vulnerable point of the lining and place of operational “fistula” are the location of technological joints

A similar phenomenon is observed in the underground subway tunnels. Thus, according to [5], the presence of “fistulas” on the segment of the underground subway tunnel led to the removal of the water-sand mixture, the volume of which increased from cubic centimeters per day at the beginning of the tunnel operation to several cubic meters in six months of its operation.

The analysis shows that from 60 to 90 % of the “fistula” is confined to the locations of technological seams.

The study of leaks revealed a pattern of their development over time. Fig. 4 presents the results of data processing on the occurrence of leaks during a number of years in the tunnels of the Tbilisi metro (curve 1) and in the Moscow collector tunnels (curve 2). The obtained dependences show that the formation of leaks in the lining of underground structures decreases over time, despite the fact that the previous leaks were carefully sealed and could not serve as “discharge openings” for the heads and flows of underground water.

3. Drawdown of the tray and underground structures. Sediment of tray, mainly occurs in the places of carrying out of the ground. The formation of cavities under the tray of the underground structure violates the static mode of operation of the lining and leads to precipitation.

Figure 5 shows the dependence of the drawdown of the underground tunnel on the volume of the excavated soil obtained by the author on the basis of the analysis of the materials of the tunnel lining survey. As follows from the graph, the value of precipitation increases parabolic in time, which leads to increasing cracking of the tunnel tray.

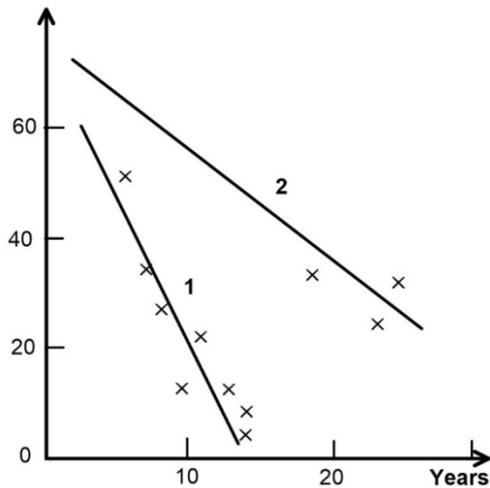


Figure 4. Reduction of leak formation through the lining of the underground structure in time: 1 - Moscow collector tunnels, 2 - Tbilisi metro tunnels.

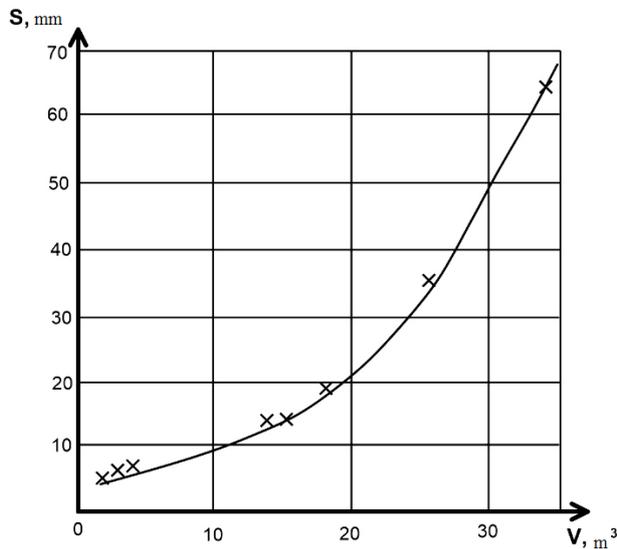


Figure 5. The dependence of the tunnel subsidence S on the amount of washed sand V .

4. Ellipticity observed in ring reinforced concrete or cast iron linings. The maximum deviation of the diameter of the tunnel lining from the design should not exceed ± 50 mm, but in practice the deviation is greater [1,2,4]. Along with the ellipticity of the rings, their displacement can be observed, reaching 70-80 mm.

5. Collector tunnels are subject to the erosion of the tray, associated with the abrasive action of solids, characteristic of the masses flowing through the tunnel. The effect of abrasives is exacerbated by the presence of “fistula”, cracks and chemical effects, which leads to a weakening of the material and the design of the tray.

6. The fallout of individual pieces of concrete from the consolidated part of the lining of underground structures.

Thus, despite the high requirements for the design and production of works in underground construction, the lining of underground structures have a number of significant defects, which in a short time lead to the failure of facilities and expensive repairs, ranging from 25 to 100% of the cost of the underground construction.

Opening of the mechanism of formation of defects in the lining allows to develop measures to prevent their formation, reduce the cost of operation and construction of underground facilities in the city.

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