Analysis of the structures in water treatment and sanitation facilities for their strengthening

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Abstract. The destruction of water treatment and wastewater treatment plants occurs under a number of factors, which include: precipitation affects the external parts of structures, moisture penetrates into the body of the structure and beyond it, weather conditions: variable temperatures, weathering, biological effects, ultraviolet radiation lead to destruction any building material. The main reasons of destruction and damage to building structures in various water treatment and wastewater disposal facilities are discussed, the most effective ways for eliminating these damages are provided in this article. The calculation substantiation of the supporting structures reinforcement namely reinforced concrete slabs in water treatment structures is carried out.

1. Introduction

The destruction of water treatment and wastewater treatment plants occurs under a number of factors, which include: precipitation affects the external parts of structures, moisture penetrates into the body of the structure and beyond it, weather conditions: variable temperatures, weathering, biological effects, ultraviolet radiation lead to destruction any building material. Water in the upper layers of the soil: seasonal moisture that accumulates in soils adjacent to external walls and foundations, groundwater: in the presence of a high level of groundwater (above the base of the foundation), underground elements of structures are constantly exposed to the negative effects of moisture, capillary moisture: water absorbed building material of underground structures in the absence or destruction of waterproofing, condensed moisture: not saturated with moisture building material has the ability to absorb water from atmospheric water air, and with it aggressive substances in relation to the material. Dynamic impact and abrasive wear: wastewater carries a large mass of sand with high hardness, therefore, they have abrasive effects on the internal surfaces of structures. As a result of the work of elevators, silt-scrapers, gates and other mechanisms, abrasive wear of the bottom, the heads of sedimentation tanks and other elements also occurs. Gas corrosion: in places where hydrogen sulfide is released, thionic bacteria form mass accumulations; sulfur is formed and deposited from hydrogen sulfide in bacterial cells, oxidized by these microorganisms to sulfuric acid, which leads to corrosion of reinforced concrete structures. A typical scheme of a complex of treatment facilities are shown on Figure 1.
2. Materials and Methods

Aerotanks, pre-aerators, sludge thickeners, distribution channels are subject to destruction under the influence of water streams saturated with impurities, solutions, bacteria vital products and high levels of various gases. Receiving chambers, distribution trays, sand traps are most susceptible to destruction under the influence of wastewater aggression and abrasive wear.

These structures are dominated by the following types of defects and destruction: destruction of the protective concrete layer, reinforcement exposure and corrosion, joints depressurization, cracks and active leaks, subsidence and peeling of the blind area.

Primary and secondary sedimentation tanks, sludge compactors, distribution chambers and trays are subject to destruction under the influence of dynamic and abrasive loads of aggregates and mechanisms, aggression of wastewater and emitted gases. These structures are dominated by the following types of defects and destruction: destruction of the concrete protective layer, reinforcement exposure and corrosion, joints depressurization, cracks and active leaks, subsidence and destruction of the blind area.

In primary and secondary sedimentation tanks, sludge compactors, distribution chambers, and repair trays, it is necessary to use compositions that exclude shrinkage, are similar in nature to the base material, are resistant to carbonization, have high water resistance, are resistant to chloride penetration, and have the required workability. Such materials include: carbon fiber-based composite materials, a one-component cement active anticorrosive coating to protect steel reinforcement and increase adhesion to concrete substrates, a high-strength dry mix of a thixotropic type containing polymer fiber, a non-shrink dry mix of a thixotropic type containing a polymer fiber, non-shrink, non-shrink fiber thixotropic type mixture containing flexible chromium-nickel and polymer fibers, non-shrink quick-hardening bulk mixture, non-shrink quick-type filler mixture comprising polymer fiber.

For the installation of metal structures subject to high loads, in conditions of high humidity and aggressive environmental influences, the use of traditional embedded parts or mechanical anchors leads to their rapid destruction due to corrosion. Under these conditions, it is advisable to apply chemical anchors indifferent to these influences, which include a two-component composition on an epoxy basis for fixing anchors subject to high loads. For waterproofing and protection, it is necessary to use coatings with high resistance to chemical and biological influences, with high physical and mechanical properties. Different parts of the structure, bottom or walls, surface, underwater or zone of variable water level, are exposed to different types of influences, therefore, the types of coatings and requirements for them also differ. Rigid compositions: special sulfate-resistant waterproofing material to protect concrete structures from the effects of sewage water, a penetrating cement-based dry mix for concrete compaction and waterproofing of structures. Elastic crack resistant coatings, two-component elastic fiber reinforced coating, two-component elastic coating on an epoxy-polyurethane base. To seal active joints that open when seasons change, as well as a result of filling or emptying tanks, it is
advisable to use a highly elastic chemical-resistant, rot-resistant insulation tape based on a thermoplastic elastomer and injection polymer compositions.

Foundations, blind area, basement, facade walls of industrial buildings are exposed to atmospheric precipitation, temperature extremes, atmospheric and industrial gases. Supporting structures, flooring and floor slabs, equipment foundations and floors are subject to man-made influences inside industrial buildings.

The following types of defects and destruction prevail at these structures: through cracks in the walls and partitions, chips and cracks in columns, trusses, beams, equipment foundations, peeling of the concrete floor surface, destruction and subsidence of the blind area, peeling and blistering of protective paint coatings.

In production buildings and workshops for repair, it is necessary to use compositions that exclude shrinkage, that are similar in nature to the base material, are resistant to carbonization, have high water resistance, are resistant to chloride penetration, and have the required workability. Such materials include: carbon fiber-based composite materials, a one-component cement active anticorrosive coating to protect steel reinforcement and increase adhesion to concrete substrates, a high-strength dry mix of a thixotropic type containing polymer fiber, a non-shrink dry mix of a thixotropic type containing a polymer fiber, non-shrink, non-shrink fiber thixotropic type mixture containing flexible chromium-nickel and polymer fibers, non-shrink quick-hardening bulk mixture, non-shrink quick-type filler mixture comprising a polymer fiber, a mixture of non-shrink quick-type filler with a low modulus of elasticity, comprising a polymer fiber, non-shrink cement-early plasticized, high strength and fast setting epoxy.

For decorative protection of load-bearing and enclosing structures of buildings, it is necessary to use coatings with resistance to technogenic and atmospheric gas influences, having physical and mechanical properties. These include elastic crack-resistant coatings, a two-component elastic fiber-reinforced coating, and one-component coatings on an acrylic basis. To seal active joints that are exposed, it is advisable to use a highly elastic chemical-resistant, resistant insulation tape based on a thermoplastic elastomer and injection polymer compositions. For urgent stopping of active leaks, sealing cracks and structural joints, it is necessary to use a hard-hardening cement mixture.

3. Results

The surveyed facility is a tank-reservoir designed for sludge of drinking water. The structure was designed with a total length of 84 m, a width is 24 m, a clear height of 5.2 m to shelves, 4.8 to the slabs edges. The construction was erected mainly above ground level with a soil embankment. Inspection necks (Ø1.56 m), ventilation shafts and air ducts (Ø300 mm) were designed in the tank slabs. The general structural scheme is a combined frame-wall (incomplete frame). The frame is made of precast concrete elements.

The foundation thickness is 160 mm, on concrete preparation of 100 mm on a natural base, with shoes for walls, partitions and columns. The base plate is made with a slope. The outer walls thickness is 220 mm, the columns are 300x300 mm and 350x300 mm in increments of 3x6 m and 3x3 m, the coating is bezel-less of 460 mm thick ribbed plates (along the edge) with dimensions of 3x6 m. The plates are supported by columns and external walls. The frame stability and immutability are provided in the transverse and longitudinal direction by the joint work of walls, columns, partitions and floor slabs. During the technical inspection of the building, the following defects of the slabs were revealed: there was insufficient thickness of the concrete protective layer, glow, reinforcement corrosion, individual places of concrete chips, delamination in the concrete protective layer on the inner faces of the slabs shelves, corrosion of individual reinforcement rods in the shelf up to 7% of the cross section, leaks at the joints of slabs and places where the slabs support the walls, corrosion up to 100% of the cross-section. The reason for the overall decrease in the bearing capacity of the coating slabs is corrosion of the reinforcement and defects in the concrete. In accordance with normative it was found that the elements of precast concrete
cover are in a limited-operational technical condition. Figures 2–5 show characteristic defects of reinforced concrete ribbed slabs. There is the load collection on the slab are in the Table 1.

**Figure 2.** Insufficient thickness of the protective concrete layer, surface corrosion of reinforcement in slabs.

**Figure 3.** Carbonation and leaks at walls and floor slabs joints, at the floor slabs seams

**Figure 4.** Crack opening up to 0.5 mm in the middle edge of the floor slab

**Figure 5.** Chipped concrete, reinforcement corrosion
Table 1. Coating load collection

| Element                                | Thickness s, m | Density, kg/m³ | Standard load, kg/m² | Overload ratio | Estimated load, kg/m² |
|----------------------------------------|----------------|----------------|----------------------|----------------|-----------------------|
| Cement and sand screed                 | 0.03           | 54             |                      | 1.1            | 59                    |
| Waterproofing on bituminous mastic     | 0.01           | 10             |                      | 1.1            | 11.0                  |
| Soil                                   | 1.0            | 1800           |                      | 1.1            | 1980                  |
| Total constant load, kg/m²             |                |                | 1864                 |                | 2050                  |
| Temporary load, kg/m²                  |                |                | 400                  | 1.2            | 480.0                 |
| Total (constant and temporary)         |                |                | 2264                 | 1.125          | 2530                  |

Reliability coefficient for responsibility γ₉ is 1. Reliability coefficient for responsibility (2nd limiting state) is 1. The design solution and the calculated cross-section of the slab is presented in Figure 6.

![Figure 6. Constructive solution and design section](image)

b = 240 mm. h = 450 mm. b₁ = 3000 mm. h₁ = 80 mm. a₁ = 55 mm. a₂ = 50 mm. The main characteristics of the slab reinforcement are shown in the Table 2.

Table 2. The main reinforcement characteristics.

| Reinforcement | Class | Working conditions coefficient |
|---------------|-------|--------------------------------|
| Longitudinal  | A400  | 1                              |
| Transverse    | A300  | 1                              |

There is the specified reinforcement in the Table 3.

Table 3. The specified reinforcement

| Area | Length (m) | Reinforcement | Section |
|------|------------|---------------|---------|
| 1    | 3          | S₁ - 2Ø18, second row 2Ø18 |         |
|      |            | Clearance between rows is 32 mm. S₂ - 15Ø8. |         |
|      |            | Transverse reinforcement along the Z axis 2Ø10, transverse reinforcement pitch 200 mm |         |
Type of concrete is heavy. Concrete class is B22.5. The concrete density is 2.5 T/m³. Hardening conditions is natural. The coefficient of hardening conditions is 1. The coefficients of the concrete working conditions are shown in the Table 4.

Table 4. The coefficients of the concrete working conditions

| $g_{h2}$ | long-term load accounting | resulting coefficient without $g_{h2}$ |
|---------|---------------------------|----------------------------------------|
|         |                           | 0.9                                    |
|         |                           | 1                                      |

Crack resistance category - 3. Construction operating conditions: Indoors. Concrete humidity mode is natural. Permissible crack opening width: short opening is 0.4 mm, long opening is 0.3 mm. Loading 1 is permanent. The data of constant load 1 is shown in the Table 5.

Table 5. The data of constant load 1

| Load type | Value | The coefficient of inclusion own weight |
|-----------|-------|----------------------------------------|
| $g_{h2}$  | 0.822 | T/m 1.1                                 |

Loading 1 is permanent. Reliability coefficient for load is 1.1. The long part coefficient is 1.

Figure 7. The calculation results

Loading 2 is permanent. Table 6 shows the data of constant load 2.

Table 6. The data of constant load 2

| Load type | Value | The coefficient of inclusion own weight |
|-----------|-------|----------------------------------------|
|           | 6.15  | T/m length = 6 m                        |
Loading 2 is permanent. Reliability coefficient for load: 1.1. Ratio of the long part: 1.

Figure 8. The calculation results

Load 3 is a temporary long-acting. There is the data of constant load 3 in the Table 7.

Table 7. The data of constant load 3

| Load type | Value | Inclusion own weight coefficient |
|-----------|-------|---------------------------------|
| m         | 1.44 T/m | length = 6 m                   |

Load 3 is a temporary long-acting. Reliability coefficient for load is 1.1. Ratio of the long part is 1.

Maximum bending moment

Cutting force corresponding to the maximum bending moment

Figure 9. The envelope of $M_{\text{max}}$ by the values of the calculated loads
Minimum bending moment

Cutting force corresponding to minimum bending moment

Figure 10. The envelope of $M_{\text{min}}$ by the values of the calculated loads

Maximum cutting force

Bending moment corresponding to maximum cutting force

Figure 11. The envelope of $Q_{\text{max}}$ according to the design load values

Minimum cutting force

Bending moment corresponding to minimum shear force

Figure 12. The envelope of $Q_{\text{min}}$ according to the design load values
Maximum bending moment
cutting force corresponding to maximum bending moment

Figure 13. The envelope of $M_{\text{max}}$ for the values of standard loads

Minimum bending moment
cutting force corresponding to the minimum bending moment

Figure 14. The envelope of $M_{\text{min}}$ for the values of standard loads

Maximum cutting force
bending moment corresponding to maximum cutting force

Figure 15. Envelope of $Q_{\text{max}}$ values according to standard loads
Minimum shear force

Bending moment corresponding to minimum shear force

**Figure 16.** The envelope of $Q_{\text{min}}$ values according to the values of standard loads.

### 4. Discussion

The support reactions are presented in the Table 8.

**Table 8.** The support reactions

| Supporting reactions | Strength in support 1 | Strength in support 2 |
|----------------------|-----------------------|-----------------------|
| by criterion $M_{\text{max}}$ | 19.046 T | 19.046 T |
| by criterion $M_{\text{min}}$ | 19.046 T | 19.046 T |
| by criterion $Q_{\text{max}}$ | 22.934 T | 19.046 T |
| by criterion $Q_{\text{min}}$ | 19.046 T | 22.934 T |

The calculation results are presented in the Table 9.

**Table 9.** The calculation results

| Utilization rate | Check |
|------------------|-------|
| 0.75             | Strength at ultimate moment of section |
| 0.591            | Crack opening width (short-term) |
| 0.789            | Crack opening width (long) |
| 0.621            | Strength along an inclined strip between inclined cracks |
| 0.943            | Inclined crack strength |
| 0.634            | Stresses in transverse reinforcement |
| 0.546            | The width of inclined cracks opening (short-term) |
| 0.728            | The width of inclined cracks opening (long) |

The materials plot for bending moment is shown in Figure 17.

**Figure 17.** Materials diagram for the bending moment
Estimated reinforcement does not exceed the actual one. The calculation results do not ensure compliance with the requirements for strength and deformation of both the system as a whole and individual elements. It is necessary to carry out work on strengthening reinforced concrete slabs.

5. Conclusions
The main causes of destruction and damage to building structures of various water treatment and sanitation facilities were considered and analyzed in this article, the most effective ways to eliminate them were given, a calculation justification of the strengthening of load-bearing structures - reinforced concrete coating slabs was carried out. In this case, the characteristic features of water treatment and sanitation facilities were taken into account.

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