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V.I. RIMSHIN[1,4], V.L. KURBATOV[2], V.T. EROFEEV[3], E.S. KETSKO[4]
[1]Moscow State University of Civil Engineering (MGSU), Moscow, Russia
[2]North Caucasian branch of Federal state Budgetary Educational Institution of higher Professional education «Belgorod state technological University Named after V.G. Shukhov», MineralnyeVody, Stavropol Territory, Russia
[3]Federal State Budgetary Educational Institution of Higher Education «National Research Ogarev Mordovia State University», Saransk, Republic of Mordovia, Russia
[4]Research Institute of Building Physics of the Russian Academy of Architecture and Building Sciences, Moscow, Russia

DEGRADATION DAMAGES SURVEY OF THE SILT RESERVOIR STRUCTURES

Abstract. *The aim of this work is to obtain information about the condition of the sludge tank supporting and enclosing building structures, identifying and fixing existing defects in order to assess their possible impact on structures during its further operation. Archival surveys were carried out, site documentation was selected and studied, load-bearing structures engineering measurements were carried out, building structures were inspected, and the structural condition was photographed selectively, graphic materials were made, technical conclusions were drawn up with conclusions and recommendations for further structures safe operation in order to achieve this goal. The technical surveying included a building structures external examination with damages fixation. The structures general technical condition of the, the presence and nature of the defect's propagation were previously visually recorded, and then refined using measuring equipment. Verification calculations were also carried out with the design and current load analysis on the sludge tank elements, and the tank supporting structures concrete strength was determined by the ultrasonic method.*

Keywords: *silt reservoir, load-bearing structures of the tank, technical condition assessment, verification calculations, non-destructive method for assessing the strength.*

В.И. РИМШИН[1,4], В.Л. КУРБАТОВ[2], В.Т. ЕРОФЕЕВ[3], Е.С. КЕЦКО[4]
[1]НИУ Московский государственный строительный университет (МГСУ), г. Москва, Россия
[2]Северо-кавказский филиал федерального государственного бюджетного образовательного учреждения высшего образования «Белгородский государственный технологический университет им. В.Г. Шухова», г. Минеральные воды, Россия
[3]ФГБОУ ВО «Национальный исследовательский Мордовский государственный университет им. Н.П. Огарёва», г. Саранск, Россия
[4]Научно-исследовательский институт строительной физики РААСН, г. Москва, Россия

ОБСЛЕДОВАНИЕ ДЕГРАДАЦИОННЫХ ПОВРЕЖДЕНИЙ КОНСТРУКЦИЙ ИЛОВОГО ХРАНИЛИЩА

Аннотация. *Целью настоящей работы является получение сведений о состоянии несущих и ограждающих строительных конструкций илового резервуара, выявление и фиксация существующих дефектов для оценки их возможного влияния на строительные конструкции в процессе дальнейшей эксплуатации илового резервуара. Для достижения поставленной цели проведены архивные изыскания, отобрана и изучена документация по объекту, выполнена инженерная обмерка несущих конструкций, проведено обследование строительных конструкций и выполнена выборочная фотофиксация состояния конструкций, выполнены графические материалы, разработано техническое заключения с выводами и рекомендациями по дальнейшей безопасной эксплуатации конструкций. Обследование включало внешний осмотр строительных конструкций с фиксацией их повреждений. Общее техническое состояние конструкций, наличие и характер распространения дефектов предварительно фиксировались визуально, а затем уточнялись с помощью измерительной техники. Также были выполнены поверочные расчеты* *элементов резервуара с анализом проектной и действующей нагрузки на элементы сооружения илового резервуара, определена прочность бетона несущих конструкций резервуара ультразвуковым методом.*

Ключевые слова: *несущие конструкции резервуара, оценка технического состояния, поверочные расчёты, неразрушающий метод оценки прочности.*

Introduction

The sludge reservoir is non-residential, operated, underground, designed to pump sludge and to compact activated sludge. The tank has a rectangular configuration. The construction was carried out in a prefabricated solution (except the bottom which is monolithic reinforced concrete). The tank dimensions in the axes are 55.7x27.6 m. The tank has two compartments separated by a reinforced concrete wall. The height from the tank floor to the coating slabs is variable: from ≈ 4.36 m to ≈ 6.38 m to the ribbed slab shelf, from ≈ 4.13 m to ≈ 6.17 m to the ribbed slab edge. The object has one buried level with a floor mark from -4.36 m to -6.38 m. The depth is variable, from ground level is from ≈ 5.755 m to ≈ 7.795 m. The construction belongs to the 2nd responsibility level. The project was developed in 1961. The sludge tank foundation design was determined on the basis of archival design materials provided. The technical condition was determined by indirect signs - the presence/absence of defects in the surveyed building structures. The foundation is a monolithic reinforced concrete bottom. The bottom composition: 2 layers of shotcrete plaster - 20 mm grouting with cement mortar 3-5 mm with ironing, concrete coating (concrete class is B7.5), reinforced concrete slab - 160 mm, cement screed - 20 mm, bitumen coating for 2 times, concrete class is B3.5) - 100 mm, a matting layer, gravel - 100 mm, crushed stone compacted into the ground - 50 mm. The foundations for the columns are glass type, reinforced concrete, the sole sizes in terms are 1100x1090 mm, 1180x1130 mm, 1100x1100 mm, 950x950mm and 550x550 mm. The foundation depth is variable. It ranges from 5.755 m to 7.955 m. Defects and damages were not revealed during the foundation's inspection by indirect signs. The foundation reinforced concrete bottom and the foundations for the columns are in working condition. The walls are made of precast concrete blocks with dimensions of 4000x2150x(150-250) mm. There are monolithic sections in the tank corners. The tank walls are coated on the inside with shotcrete in 2 layers, treated with a layer of cement mortar 3-5 mm thick on fine sand with a surface grout. The tank walls from the outside are covered with shotcrete plaster in 1 layer 10 mm thick, coated with bitumen for 2 times. Precast reinforced concrete columns have a cross section of 250x250 mm with capitals measuring 400x400x400 (h) mm. The load from the columns is transferred to the bottom through the prefabricated glass type foundations, having an expanded support part with the sole dimensions in terms of 1100 × 1090 mm, 1180 × 1130 mm, 1100 × 1100 mm, 950 × 950 mm and 550 × 550 mm. The columns are installed in a glass on a cement-sand mortar. Manholes with dimensions ≈1230x920x1850 (h) mm are equipped for descent into the tank. The manholes walls are made of monolithic reinforced concrete, the wall thickness is 180 mm. On the axes 10-1/D, 2-8/D, 5/A-I, 1-3/A-I, reinforced concrete partitions with a thickness of 100 mm and a height of 1200 mm were installed. The inspection revealed the following defects and damage to walls and columns: concrete chips, leaks traces and mortar leaching, local damages in the stairs, the reinforced concrete partitions dismantling, clamps exposure in the column due to insufficient thickness of the concrete protective layer, destruction of the concrete wall manhole with exposure and reinforcement corrosion. The tank walls are in good technical condition. The columns are in operational technical condition. The coating is prefabricated reinforced concrete slabs with dimensions of 3480x3480x350 (h) mm, 3480x3460x350 (h) mm, 3460x3460x350 (h) mm. The coating is made of ribbed slabs with ribs along the perimeter with a total height of 35 cm and a width of 15 cm, the slab shelf thickness is 12 cm. The central slabs are angled by the columns, the slabs along the perimeter are supported on one side by the walls. The coating slab was calculated as a slab supported perimeter on beams. The ribs are reinforced in the lower (stretched) zone 2⌀18 in the upper (compressed) zone 2⌀12, the slab is reinforced in the stretched zone 2⌀10 in the central part with a 100 mm step in the support with a 200 mm step. Steel with standard resistance R_{an} = 2800 kg/cm^2 is used for reinforcement. The protective layer to the working reinforcement in the ribs is 25 mm, in the slab is 15 mm. The inspection revealed the following defects and damage to the coating slabs: reinforcement in the slab shelf exposure and corrosion, clamps exposure in the coating slab due to insufficient thickness of the protective concrete layer, leaks traces and mortar leaching due to waterproofing, a through crack in the inter-tile seam. Coating slabs are in good technical condition. Roof is operated. The roof composition is according to the project on prefabricated reinforced concrete slabs, from top to bottom: soil - 1250 mm, bitumen spread 2 times, the leveling layer of cement mortar - 5 mm, shotcrete-plaster - 20 mm. No defects were found during the inspection. The roof is in satisfactory condition. Single-section metal stairs are installed in the axes 2-3/A-B, 7-8/A-B, 10-11/A-B, 2-3 /I-K, 15-16/I-K for descent into the tank. The staircase bowstring is an equal-angle corner 75x75x8 mm, the equal-angle corner 70x70x8 mm (in the places of corrosion exposure the angles are up to ≈4 mm), the steps are round steel ⌀25 mm-⌀28 mm (in places of corrosion up to ≈ ⌀14 mm). Damages in the staircase fastening area, corrosion in the weld zone due to corrosion, metal elements delaminating corrosion were revealed during the technical survey., It was revealed at the measurement sites that, due to the corrosion effect, the individual step rods diameter in the lower stairs part changed from ≈⌀25-28 mm to ≈⌀14 mm, and individual metal stairs were partially dismantled. The sludge tank stairs are in a limited - operational technical condition.

Results of verification calculations

Verification calculations for the sludge tank elements were performed with design and current loads on analysis. The coating loads collection is presented in table 1.

Table 1– Coating loads collection

Element	Thickness, m	Density kg/m^3	Standard load, kg/m^2	Overload coefficient	Designload, kg/m^2
Soil	1.25	1700	2125	1.15	2443.75
Bitumen spread 2 times	0.01	600	6	1.3	7.8
Cement and sand screed	0.005	1800	9	1.3	11.7
Sprayed plaster	0.02	1800	36	1.3	46.8
Reinforced concrete slab			394.3	1.1	433.7
TOTAL constant, kg/m^2			2570.3		2943.8
Temporary (snow), kg/m^2			126		180.0
Temporary, kg/m^2			50	1.3	65.0
TOTAL (permanent + temporary) kg/m^2			2746.3		3188.8

No defects and damages that reduce the structures bearing capacity were revealed during the sludge tank inspection, as well as on the strength control basis, concrete was not lower than class B20, which confirmed that precast concrete elements strength is not lower than design class B15. The concrete strength obtained during the survey was taken into account. Based on the performed verification calculations for the actually acting loads, it was found that the prefabricated cover slabs bearing capacity is sufficient to absorb the actual loads: coating slabs. g_{load} = 3188.77 kg/m^2<g_{sec} = 3330.40 kg/m^2. According to the project, the reservoir was designed for a load of 3340kg/m^2, taking into account its own weight; columns maximally loaded. N·e = 4101.55 kg·m<M_{ult} = 7557.67 kg·m. Based on the calculations, it can be concluded that the bearing capacity of all tank elements is provided under the existing load, the bearing capacity of all elements of the sludge tank is provided under the existing load. It is prohibited to store, place, install anything on the tank, as well as passing vehicles in order to prevent excess load on the tank structure [1]. Checking a rectangular section of a reinforced concrete beam bearing capacity (figure 1). Estimated values: b = 15 cm, h = 35 cm, h_0 = 32.5 cm, a = 2.5 cm.

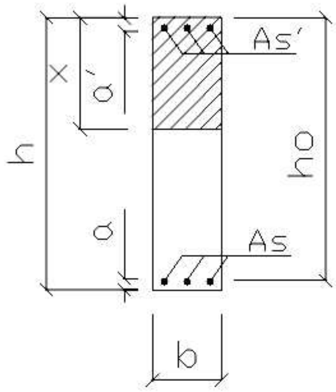

Figure 1 – The calculated cross section of the beam slab coating

The reinforcement in the compressed zone is 2 Ø18. The reinforcement in the stretched zone is 2 Ø12. Design resistance of B20 R_b = 105.3 kg/cm^3. The working conditions coefficient $\gamma_{(b,2)}$ is 0.9. The reinforcement design resistance of A240 is calculated by formula (1):

$$R_s = \frac{R_{s,n}}{\gamma_s} = 2434.78 \text{ kg/cm}^2 \quad (1)$$

Reinforcement elasticity modulus is E_s = 2,000,000 kg/cm^2. Estimated bending moment in the span is M=139987.6 kg·cm. The calculated bending moment on the supports M = 279975.1 kg·cm. The compressed reinforcement cross-sectional area is As′ =2.26 cm^2. The stretched reinforcement cross-sectional area is A_s=5.09 cm^2. The upper reinforcement in the beam center is negligible, and it was performed constructively [2-3]. The calculation for this case is performed as for sections with single reinforcement (see formulas (2) and (3):

$$x = \frac{R_s \cdot A_s}{R_b \cdot b} = 7.85 \text{ cm} < \xi_R \cdot h_0 = 26.0 \text{ cm} \quad (2)$$

$$\xi_R = \frac{0.8}{1 + \frac{R_s}{E_s} \cdot \varepsilon_{b,2}} = 0.8 \quad (3)$$

$\varepsilon_{b,2}$=5600

For calculating the rectangular sections of bent elements by the formula $x<\xi_R \cdot h_0$, the section strength is checked from the condition (4):

$$M_c = R_s \cdot A_s \cdot x \cdot (h_0 - 0.5 \cdot x) \quad (4)$$

$M_c = 354118.4 \text{ kg} \cdot \text{cm} = 3.54 \text{ t} \cdot \text{m} > M = 279975.1\ kg \cdot cm = 2.80\ t \cdot m$

The bearing capacity in the span is provided, the safety margin is 20.94%

The bearing capacity determination of a slab in a span of 1 m wide (rectangular section with a single reinforcement). Concrete is B20, R_b = 117 kg/cm^2. The reinforcement is 9⌀10. R_s= 2434.78 kg/cm^2. A_s=7.07 cm^2. a=1.5 cm. h=12 cm. b=100 cm. h_0=h-a = 10.5 cm. L=348 cm. The calculated section of the slab shelf in the span is shown in figure 2.

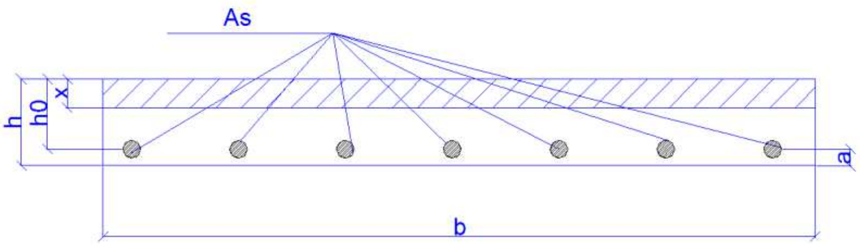

Figure 2 – Designed and calculated section of the slab shelf in the span

Concrete compressed area height is calculated by formulas (5) and (6):

$$x = \frac{R_s \cdot A_s}{R_b \cdot b} = 1.47 \text{ cm} \quad (5)$$

$$\xi_R = \frac{0.8}{1+\frac{R_s}{E_s}\cdot\varepsilon_{b,2}} = 0.636 \quad (6)$$

Relative concrete compressed area height is calculated by formula (7):

$$\xi = \frac{x}{h_0} = 0.14 < \xi_R = 0.636 \quad (7)$$

The condition is fulfilled. Section bearing capacity is calculated by formulas (8) and (9) :

$$M_c = R_s \cdot A_s \cdot x \cdot (h_0 - 0.5 \cdot x) = 168052\ kg \cdot cm = 1680.52\ kg \cdot m \quad (8)$$

$$g_n = \frac{M_n \cdot 24}{L^2 \cdot b} 33340.4 \frac{kg}{m2} > g_n^{calc} = 3188.77\ kg/m2 \quad (9)$$

The bearing capacity is provided; the safety margin is 4.25%. An additional maximum load on the slab is 141.63 kg/m^2.

Checking the eccentrically compressed reinforced concrete sections bearing capacity. Calculation of the maximum loaded column of the tank. Concrete is B20, R_b = 117 kg/cm^2. E_b = 270,000 kg/cm^2. The reinforcement is 4⌀1.6. R_s = 2800 kg/cm^2. A_s = 4.0 cm^2. a = 2.0 cm. l0 = 435 cm. h = 25 cm. b = 25 cm. h_0 = h-a = 23 cm. N = 39062.41 kN. Checking the condition l_0 h = 17.40 cm > 4cm.$\varphi = 1.2$. The eccentricity is calculated by formula (10).

$$e = e_0 \cdot \eta + \frac{h}{2} - a = 10.50\ cm \quad (10)$$

where η is calulated by formula (11).

$$\eta = \frac{1}{1-\frac{N}{N_{cr}}} = 1.45 \quad (11)$$

The force perceived by the section during the formation of cracks is calculated by formula (12).

$$N_{cr} = \frac{1.6 \cdot E_b \cdot b \cdot h}{(\frac{l_0}{h})^2} \cdot \left[\frac{0.\frac{11}{0.1+\delta}+0.1}{3 \cdot \varphi} + \mu \cdot \alpha \cdot (\frac{h_0 - a}{h})\right] = 125345\ kN \quad (12)$$

Where (see formulas (13) and (14)):

$$\mu \cdot \alpha \cdot (\frac{A_s + A_b}{b \cdot h}) \cdot \frac{E_b}{E_s} = 0.01654 \quad (13)$$

$$\delta = \frac{e_0}{h} = 0 \quad (14)$$

Accept δ = 0.209. φ = 1.2. ξ_R =0.62068. Check condition (see formulas (15) and (16)):

$$x = \frac{N - R_{sc} \cdot A_s + \sigma_s \cdot A_s}{R_b \cdot b} = 13.4\ cm \quad (15)$$

$$\xi = \frac{x}{h} = 0.58 > \xi_R = 0.62 \quad (16)$$

The column bearing capacity calculation is performed according to the formula (17):

$$N \cdot e \leq R_b \cdot b \cdot x \cdot (h_0 - 0.5 \cdot x) + R_{sc} \cdot A_s \cdot (h_0 - a) \quad (17)$$

4101.553 kg·m<7558 kg·m.

The condition is satisfied, the section strength is provided. Safety margin is 45.7%.

Checking the bearing capacity of the outer wall for permanent, temporary and special loads. Collecting loads and determining internal efforts. The normative permanent and temporary loads in structures were determined taking into account the survey results [4]. The following types of loads were attributed to constant loads: from soils, from the dead weight of the tank structures. The temporary loads included vehicles effects. Special loads and special loads combination from a fire truck were taken into account; the reliability coefficients for loads were taken equal to 1.0, the coefficient for liability is equal to 1.0, the strength materials characteristics were taken equal to their normative values [5-8]. The normative load from the fire engine weight is equal to 36 kPa for each vehicle axle, and evenly distributed load over the passage cover on a site measuring 0.6 x 0.2 m was adopted. The load was applied directly to the outer wall axis and was taken as the most unfavorable position due to the fact that there is no through passage above the tank cover. The calculation results are presented in figure 3.

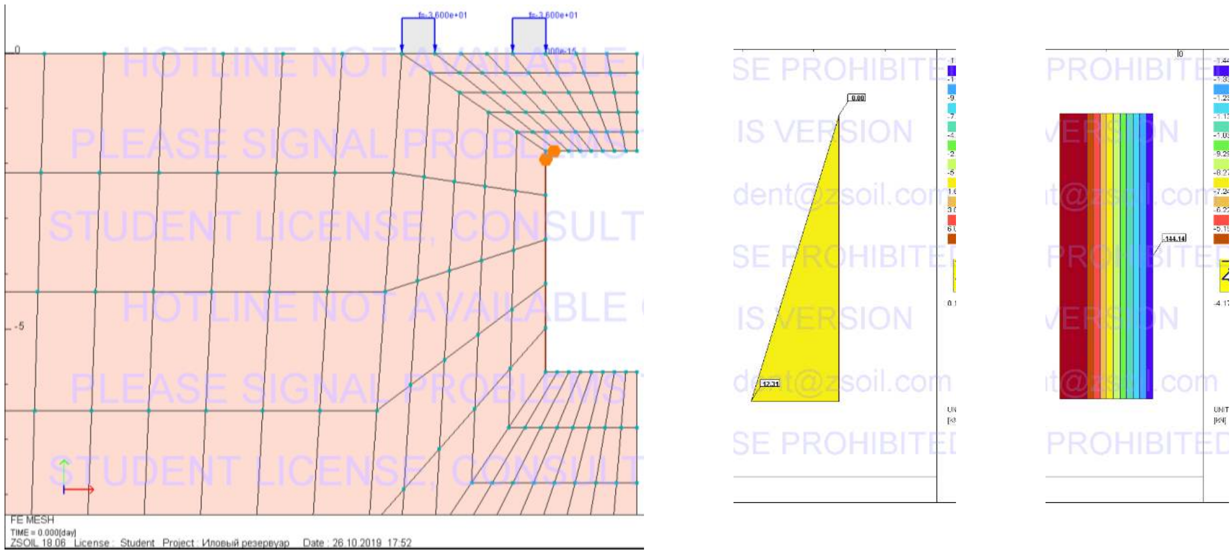

Figure 3 – Calculation results

Internal forces in the tank wall: bending moment M = 12.3 kN·m; compressive force N = 144.1 kN.

Calculation results and discussion

Concrete class is B20, reinforcement is ⌀12 A300, protective layer size is 3.0 cm, reinforcement pitch is 150 mm. Reinforced concrete slab is calculated as an eccentrically compressed element. The bearing capacity provision is possible subject to the following conditions (18):

$$N \cdot e \leq R_b \cdot b \cdot x \cdot (h_0 - 0.5 \cdot x) + R_{sc} \cdot A_{sc} \cdot (h_0 - A_{sc}) = 81.16 \text{ kN} \cdot \text{m} \quad (18)$$

The eccentric-compressed reinforced concrete elements calculation

The cross-sectional shape of the reinforced concrete element is rectangular, reinforcement is without prestressing. M = 12.30 kN·m - bending moment from the full external load action. M_l = 12.30 kN·m - bending moment from the temporary external load action. N = 144.10 kN - longitudinal force from the full load action. N_l = 144.10 kN - longitudinal force from the temporary load action. b = 100.0 cm - section width. h = 30.0 cm - section height. L = 4,000 m - element length. B20 - concrete class.a_s = 3.0 cm - the protective layer of the stretched reinforcement. a_{sc} = 3.0 cm - the protective layer of compressed reinforcement. A300 - tensile reinforcement.A300 - compressed reinforcement. A_s = 6.786 cm^2, is the cross-sectional area of the stretched reinforcement. A_{sc} = 6.786 cm^2, is the cross-sectional area of the compressed reinforcement. l0 = 2,800 m - the estimated element length. A hinged support at one end and a rigid seal at the other one is a form of supporting the element ends [9-11]. The random eccentricity e_a is 1.0 cm. The initial eccentricity of the longitudinal force application is e_0 = 9.5 cm. The compressed zone relative height is $\xi = 0.046 < \xi_R = 0.580$. The compressed zone height x is determined by option 1, and x is 1.3 cm. The distance from the application point of the longitudinal force to the tensile reinforcement gravity center is e = 21.6, cm. Strength test is N·e=31.19 kN·m (see formula (19)).

$$R_b \cdot b \cdot x \cdot (h_0 - 0{,}5 \cdot x) + R_{sc} \cdot A_{sc} \cdot (h_0 - A_{sc}) = 81.16 \text{ kN} \cdot \text{m} \quad (19)$$

31.19 kN·m<81.16 kN·m

The strength condition is satisfied. Safety factor M_{ult}/M = 2.60. The tank wall bearing capacity is provided.

Concrete strength determination by ultrasonic method. Methodology for determining strength. The reinforced concrete structures strength of is determined by the ultrasonic method using the Pulsar-2.2 device with a universal calibration curve. The concrete class in terms of compressive strength is determined in the ultrasonic method for determining strength by static assessment [11-15]. At least three speed propagation measurements of ultrasound in each direction were made at the test site, the average value in the direction (V) was recorded with the PULSAR-2.2 instrument. The average ultrasound propagation velocity in each section (V_m) were calculated, according to which, using the universal calibration dependence ($R = 0.016 \cdot V_m - 27.3$), concrete strengths were determined (R, column 5, table 2). The approximate conditional concrete class on the site is determined by the formula $B = 0.8 \cdot R$ (V, column 6, table 2). The concrete test results are presented below in table 2.

Table 2 – Results of columns and slabs concrete class determining the by the ultrasonic method using surface sounding with the PULSAR 2.2 device

No.	Design name	Ultrasound velocity, m/s	Average ultrasound velocity, m/s	Concrete strength, kg/m^2	Concrete class
1	Column	3330	3323	263,6	B20
		3270			
		3340			
		3350			
2	Column	3350	3335	265,7	B20
		3330			
		3320			
		3340			
1	Floorslab	3330	3298	259,6	B20
		3290			
		3280			
		3320			
2	Floorslab	3300	3320	263,2	B20
		3310			
		3270			
		3280			

Conclusions

Thus, it was revealed on the basis of the analytical work performed to analyze the actual technical condition that the technical condition of the examined sludge tank structure is assessed as a working condition. The exception is metal stairs - the technical condition is assessed as limited-functioning. It is recommended that all metal stairs be replaced with stainless steel stairs. Their technical condition may pass from a limited-functioning to an emergency state in case of failure to comply with the recommendations on the replacement of stairs [16-18]. In addition, verification calculations of the tank elements were performed with an analysis of the design and current load on the elements. No defects and damages that reduce the structures bearing capacity were revealed during the sludge tank inspection, as well as on the strength control basis, concrete was not lower than class B20, which confirmed that precast concrete elements strength is not lower than design class B15. The concrete strength obtained during the survey was taken into account. Based on the performed verification calculations for the actually acting loads, it was found that the prefabricated cover slabs bearing capacity is sufficient to absorb the actual loads: coating slabs. $g_{load} = 3188.77$ kg/m^2 $< g_{sec} = 3330.40$ kg/m^2. According to the project, the reservoir was designed for a load of 3340kg/m^2, taking into account its own weight; columns maximally loaded. $N \cdot e = 4101.55$ kg·m $< M_{ult} = 7557.67$ kg·m. Based on the calculations it can be concluded that the bearing capacity of all tank elements is provided under the existing load. Based on the survey results and verification calculations for the possible further reservoir operation, it is recommended to replace metal stairs with stainless steel stairs. It is recommended to restore the protective layer of concrete with increasing adhesion using Penetron technology or a specially developed project in places of the protective layer destruction, including reinforcing bars exposed and corrosion. Also, it is necessary to process walls, columns and slabs with a waterproofing composition. to remove dust and dirt from the surface, prime the crack surface with a special mortar at the crack formation site, expand the crack, rinse the resulting slurry with water under pressure, monitor the crack with mortar mixture with improved waterproofing properties with a trowel or putty knife, and protect the solution from evaporation until it is full hardening or injection crack [19-21]. It is prohibited to store, place, install anything on the tank, as well as passing vehicles in order to prevent excess load on the tank structure [22]. The outer wall bearing capacity for permanent, temporary and special loads is provided.

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Information about authors:

Rimshin Vladimir Iv.
Moscow State University of Civil Engineering (MGSU), Moscow, Russia,
doctor of technical sciences, professor, Corresponding Member of RAACS.
E-mail: v.rimshin@niisf.ru

Kurbatov Vladimir L.
North Caucasian branch of Federal state Budgetary Educational Institution of higher Professional education «Belgorod state technological University Named after V.G. Shukhov», MineralnyeVody, Stavropol Territory, Russia,
doctor of economic sciences, professor, director of the North Caucasian Branch Shukhov Belgorod State Technological University named after V. G. Shukhov.
E-mail: kurbatov_bgtu@list.ru

Erofeev Vladimir T.
Federal State Budgetary Educational Institution of Higher Education «National Research Ogarev Mordovia State University», Saransk, Republic of Mordovia, Russia,
doctor of technical sciences, professor, dean of the Architecture and Civil Engineering Faculty.
E-mail: fac-build@adm.mrsu.ru

Ketsko Ekaterina S.
Research Institute of Building Physics RAASN, Moscow, Russia,
postgraduate student.
E-mail: kkuzzina@mail.ru

Информация об авторах:

Римшин Владимир Иванович
НИУ Московский государственный строительный университет (МГСУ), г. Москва, Россия,
доктор технических наук, профессор, член-корреспондент РААСН.
E-mail: v.rimshin@niisf.ru

Курбатов Владимир Леонидович
Северо-кавказский филиал федерального государственного бюджетного образовательного учреждения высшего образования «Белгородский государственный технологический университет им. В.Г.Шухова», г. Минеральные воды, Россия,
доктор экономических наук, профессор, директор Северо-Кавказского филиала «БГТУ им. В.Г.Шухова».
E-mail: kurbatov_bgtu@list.ru

Ерофеев Владимир Трофимович
ФГБОУ ВО «Национальный исследовательский Мордовский государственный университет им. Н.П. Огарёва», г. Саранск, Россия,
доктор технических наук, профессор, декан архитектурно-строительного факультета.
E-mail: fac-build@adm.mrsu.ru

Кецко Екатерина Сергеевна
Научно-исследовательский институт строительной физики РААСН, г. Москва, Россия,
аспирант.
E-mail: kkuzzina@mail.ru