Assessment of the residual load-bearing capacity of reinforced concrete structures in service based on their physico-mechanical properties

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Abstract This section discusses the service life of reinforced concrete structures according to design data until their reliability decreases to the permissible limits (see point "Б" in Figure 1.1). In this case, the actual climatic conditions of the location of the structure and the expected static-dynamic loads are taken into consideration. At this stage, the residual resource of the bearing capacity of the beams and slabs is predicted based on the first limit state calculation, strength and bearing capacity. The criteria and requirements of construction norms and rules [1] are utilized in the calculation, and the change in the characteristics of concrete and vivacity over time is likewise envisaged . The design loads are: permanent and temporary loads regarding HK, strength and durability being considered.

Keywords: serviceablity, stability, deformation, elasticity, deformation-plastic.

Introduction

While examining reinforced concrete structures, one of the important factors is the determination of the durability indicators of the structure, which determine the performance of reinforced concrete structures during operation. This problem is surmounted in the work by developing a methodology for determining the residual resource and operation of reinforced concrete structures based on the physical and mechanical characteristics of concrete and reinforcement. The paper elaborates the methodology for determining the residual resource and suitability of a structure based on the change in the strength characteristic over a certain period of time, the ability to resist external influences during a certain time interval (during the operation period) of static and dynamic loads acting over a certain time interval (during the operation period), as well as the characteristics of physical wear caused by structural changes as a result of atmospheric exposure over the years, and the gradual degradation of the structure (we are referring to concrete erosion and metal corrosion). This methodology allows us to determine the durability of reinforced concrete structures during the operation period. That is, to determine the load-bearing capacity of the structure due to its aging and changes in the parameters of structural changes over the years. Thus, by using this methodology, we are able to determine the period of safe operation (without failures) of reinforced concrete structures and assess the risk factors expected during their further operation (degree of failure) and timely identify restoration and strengthening measures with intent to prevent the expected development of destructive processes in reinforced concrete.

Prediction of Concrete Strength Variations (Considering the Concrete Degradation Model with Freeze-Resistance Factors)

$R_ბ$ - Concrete Load-bearing Capacity and modulus of elasticity

$E_ბ$- degradation of ductility modulus during *t* – years is calculated by the formula below:

$$R_{B1} = \gamma_{Ra} \cdot R_B , \qquad (3.1)$$

$$E_{B1} = \gamma_{Ra} \cdot E_B , \qquad (3.2)$$

Where R_B და E_B represent, respectively, the concrete's design resistance and the ductility model;

γ_{Ra} and γ_{Ea} – Coefficient of serviceability calculating concrete constructions:

INDEX	Water saturation state	Construction zone	Very strict E= 300		strict F= 300		moderate F= 200	
			D_R	D_E	D_R	D_E	D_R	D_E
1A	water-saturated state	Transitional water level (failure of waterproofing, facilitated water drainage, water infiltration) in the deformed joint zone, and the flaking of the tiles	13,5	20,9	6,0	9,6	3,0	4,8
1B	Episodic water saturation process	Upper water zones (concrete surface exposed to atmospheric influences), facade surfaces (structural supports)	9,0	13,8	3,0	4,6	1,6	2,5
1C	The state governed by air humidity	Water-covered zones, surfaces under influence of atmospheric precipitation	4,5	6,0	2,0	3,0	1,0	1,5

$$\gamma_{R(B)a} = 1 - K_S K_t \cdot \Delta_{R(b)} \omega t, \quad (3.3)$$

where K_S –the coefficient depended on the aggressive state of water.

$K_S = 1{,}0$ – when concrete comes into contact with fresh water.

$K_S = 1{,}25$ – concrete comes into contact with salty water.

K_t - coefficient corresponding to the transition from the properties of a cube to a prism, where $K_t = 1{,}675$;

D_R and D_E –represent complexies that affect concrete during freeze-thaw cycles at given humidity conditions (see table 3.1);

W – shows the level of destructive process velocity.

t – period of exploitation according to years;

D_R and D_E –meanings of these complexes are calculated according 3.1 and 3.2 schedules in lights of probability – by providing 0,95.

The development of destructive processes in concrete products is posed by the level and type of stress state, the ability of concrete to absorb water, and the aggressive environment in contact with the concrete product. The following ought to be given due regard when calculating concrete constructions:

a) Alterations in the structural characteristics and baseline parameters of concrete, including its strength, frost resistance, and water saturation, are discerned.

Schedule 3.1

b) Environment effect (climate conditions, salinity of water and environment);

c) Frequency of temperature variations within 0°C at each cycle;

d) The level and type of tensed condition.

At the same time, two processes occurring within the concrete are taken into consideration.

– The assessment of strength over a span of 5 to 20 years, as stipulated by the required standards, is conducted.

– Destruction of concrete products during the period of exploitation;

– D_R and D_E are the values of parameters for water saturation and frost resistance conditions, as defined by the standards;

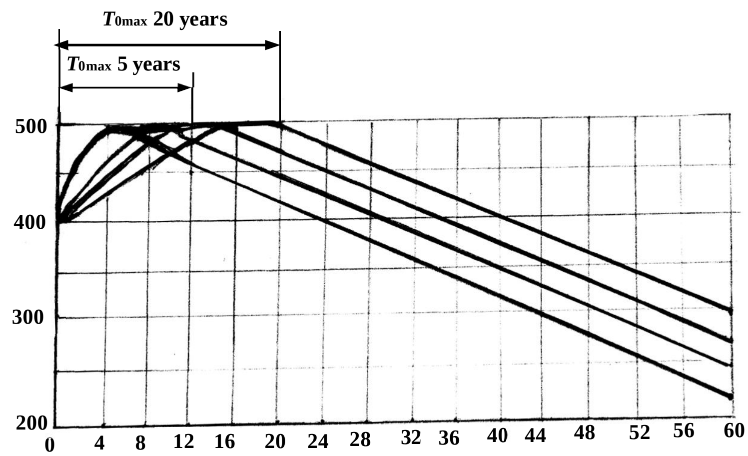
hedule 3.2

W – The value of parameter, taking into consideration frost resistance and tensed state

$W \cdot 10^3$

	$\frac{\sigma_{min}}{R_b}$	F= 200		F= 300	
		compression	streching	compression	streching
1	0,01	4,86	5,00	3,28	3,33
2	0,05	4,42	5,02	3,04	3,34
3	0,10	4,04	5,06	2,84	3,36
4	0,15	3,79	5,14	2,70	3,39
5	0,20	3,64	5,26	2,60	3,45
6	0,25	3,56	5,42	2,55	3,52
7	0,30	3,54	5,63	2,53	3,60
8	0,35	3,59	5,90	2,53	3,71
9	0,40	3,70	6,25	2,58	3,85
10	0,45	3,90	6,69	2,66	4,01
11	0,50	4,21	7,27	2,78	4,21
12	0,55	4,68	8,04	2,95	4,46
13	0,60	5,38	9,09	3,21	4,76
14	0,65	6,08	10,60	3,54	5,14
15	0,70	6,80	12,90	3,88	5,63
16	0,75	7,52	16,84	4,23	6,27
17	0,80	8,23	25,00	4,57	7,14

The characteristic strength of concrete, as stipulated by construction standards and regulations, ranges from 5 to 20 years, beyond which a decline in strength properties occurs. The graph depicting the time-dependent behavior of strength over the years is shown in Figure 3.1



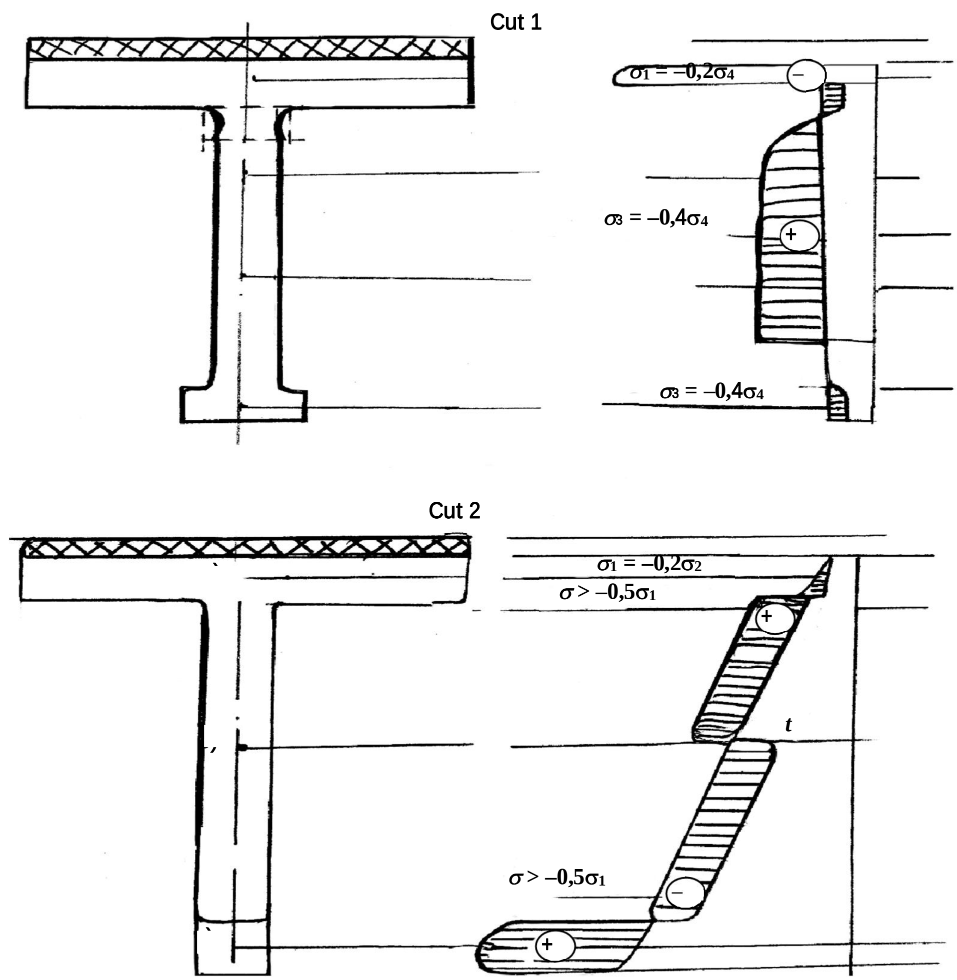
picture. 3.1. Age of concrete structure T_0- years

3.2. The stress in concrete elements owing to sharp temperature fluctuations

Sharp increases or decreases in environmental temperature lead to the development of normal tensile or compressive stresses in concrete elements. Such stresses occur in the slab, wall, and lower part of the beam. The magnitudes of these stresses are considered when evaluating the stressed-deformed state of the structure during the calculation of strength and load-bearing capacity [19].

The determination of stresses is implemented in the following sequence:

- The cross-section is divided into individual elements;
- The thickness value of the elements in the cross-section, dj, is determined;
- The conditional calculated temperature, tj, is computed for the elements under conditions of sharp temperature increase or decrease;
-
- The stress value, σ, is calculated for each element
- The division of the cross-section of the product into elements is shown in Figure 3.2. Each cross-section is conventionally divided into the following elements: reinforced concrete slab, reinforced concrete column flange, lower column flange or part of the lower base of the wall, the height of which is equal to the wall thickness.



picture 3.2. Graphs of calculated voltages

thickness of cross-sectional elements are calculated by the formula:

$$\delta_i = \frac{2 f_i}{S_i} \text{, meter}$$

where f_i – cross-sectional area of a single element,1meter^2.

f_i - The perimeter of a product's cross-section that is in contact with the surrounding air.

Conditionally calculable t(temperature) is defined according to 3.3 schedule:

Schedule 3.3

Specifically calculated temperature values of cross-sectional elements:

d_i	∂	0,02	0,04	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,9	1,1
t_i	C°	9,3	8,5	6,8	5,0	3,7	2,7	2,0	1,4	1,0	0,5	9

The tensile stress at the center of the rib in prestressed coils may be calculated utilizing the formula presented herein : $\sigma = \alpha E \cdot \Delta t \cdot P$, , kgf/cm² (3.5)

where $\alpha = \dfrac{1}{(1+f_m/f_\alpha)m}$ – Indicator of the mass of the element, f_m – cross-sectional area of the mass, whereas f_α – the rest part of the cross-sectional area; m – correcting coefficient, which is shown on picture. 3.2 for calculating schemes. 2,5 is got On first cut 1and 2 –for second cut,; E – modulus of concete elasticity.

Δt emerges as change in temperature between the element of small mass and average temperature. The average value of temperature of the rest elements are calculated by the outlined formula:

$$t_{Med} = \frac{\sum_{i=1}^{n} f_2 \cdot t_2}{f_a}, \quad (3.6)$$

n is the amount of elements prevailing in the cross-section besides the elemnts possesing masses of– f_m (in the case of picture. 3.2 n = 2).

Temperatural voltage in need of calculation subjects to the formula

$$\sigma_t = \sigma_Z \cdot S_1 \cdot S_2 \cdot S_3 \cdot S_4 , \quad (3.7)$$

where, σ -the value of voltage according to Fig. 3.2 drawing from the dependance (3.5). S_i is correcting coefficient.

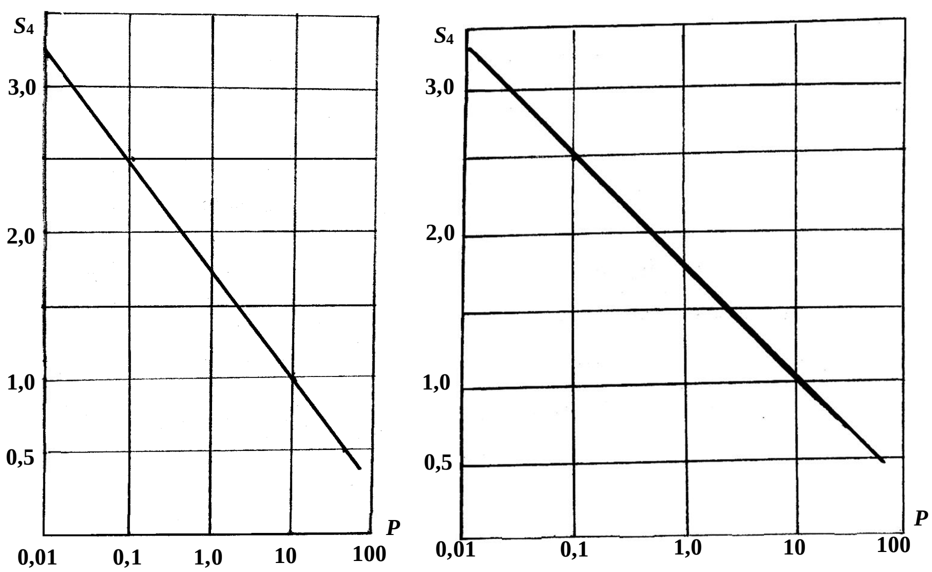
Sharp increase and decrease are defined in every cross-section. At the same time, it should be noted that the value of S_1 is respectively taken from the range $-1{,}0 \div +1{,}3$.

S_2 – coefficinet is taken from 0,0374A by envisaging climatic conditions, where A represents the diurnal temperature variation amplitude, in accordance with construction standards and regulations

S_3 – is taken according to the state of the coil and cross-section. 1,0 utilized for average diameter of ∅.

∅ –for outer coils S_3 = 1,25.

S_4 – is taken This coefficient is taken according to different values of stresses induced in the cross section and is obtained as 0.5; 1; 0.5; 1.75; 3.0 in the case of repetition: 50 times, 10 times and 1 time per year and 1 time within 50 years (see Fig. 3.3).



(1 times100 years) (1times 10 years) (once in a year) (100 times in a year)

Fig. 3.3. the probability of calculating voltage repetition

The calculated values of temperature stresses are taken into account:

$K_4 =$ When calculating slabs, when adding the Sp-value, taking into account the compressive stress, when 0.5;

$K_4 =$ When checking the serviceability of coils, when attaching the Sp-value in the direction of the main stresses, we take into account the values of the main tensile and compressive stresses, on the coil wall, when 1.75;

$K_4 =$ When determining the stresses in the compressed area in coils, we take into account the addition of the Sp-value, when 2.5

3.2.5. This is approximately the repetition

Calculating tempretura; voltage values can be determined by the following formula:

$$\sigma_t = \sigma_Z \cdot S_1 \cdot S_2 \cdot S_3 \cdot S_4 , \quad (3.7)$$

where σ- voltage value which is defined by structural diagrams of voltage (Fig. 3.2) and (Fig. 3.5) concentration of exhaust in the tile (W_t) derived from Dakhans . *DT* – rested resource. S_i is correcting coeficcient.

Each cross-section is considered for two types of impacts and takes into account a sharp decrease and increase in air temperature. At this time, the value of the magnitude in the temperature range from -1.0 to +1.3 is taken into account.

S_2 – coefficient presupposes the characteristics of climatic regions and is taken from:

$$S_2 = 0{,}0374A, \quad (3.8)$$

where *A* is diurnal temperature change amplitude and is taken according to region climate conditions.

S_3 – The coefficient takes into account the location of the coil in the cross-section of the product.

∅ For coils with medium cross-section $S_3 =$ 1,0.

∅ –for outer coils $S_3 =$ 1,25.

The coefficient takes into account the degree of stress repetition and is taken with values equal to 0,5; 1,0; 1,75; 3,0 depending on how many times the repeated reaction occurred, 50; 10 and 1-times in a year and 1-times in 50 years (see. Fig. 3.3).

– When calculating slabs, the value of the compressive stress σ_3 must be additionally taken into account.

3.3. Prediction of concrete carbonation

The carbonation characteristics of concrete are obtained according to the values given in the table (Table 3.4), which are obtained on the foundation of statistical analysis of experimental results conducted at the test site of various reinforced concrete structures.

„*a*" The importance of the protective layer thickness on the carbonation time of concrete products– $T_{carb.}$ Determined by the formula:

$$T_{kar\ b} = m_1 \cdot m_2 \cdot m_3 \cdot m_4 \cdot \frac{a}{K}, \quad (3.9)$$

Where *a* is the thickness of the concrete protective layer specified in the project in mm;

K – normative value of the velocity of carbonization mm/year (schedule3.4);

m_1 –Coefficient selected according to the type of construction; (concrete compression ratio); $m_1 = 0{,}6$ – For foundry columns with conventional reinforcement;

$m_1 = 1{,}0$ – For prestressed structures;

m_2 – Coefficient according to surface layout;

$m_2 = 2{,}0$ –For medium surfaces of slabs and coils;

$m_2 = 1{,}0$ – For facade surfaces;

m_3 – coefficient depending on the aggressiveness of the air and is taken as: 2.0; 1.3 and 1.0 – for environments with a weak, medium and high degree of aggressiveness;

m_4 – coefficient, which takes into account the size of the protective layer on the bottom and side surfaces of the plates and coils;

$m_4 = 1{,}5$ $-T_s = 3 \div 7$ – For year-round insulative fencing;

$m_4 = 3{,}0$ For protective labor working throughout the year $T_s = 30$ (when $t < 3$ years $m_4 =$ 1, when $t = 7 \div 30$ year defined by interpolation).

Schedule 3.4

Normal values of carbonation of concrete products (for aggressive environments)

nomination	raise	normal	low	remark
Concrete strength	0,86	B 82	< 0,82	–
Watertightness stamp B	W B8-B6	B 4	< B 4	
Carbonization speed K mm/year	0,25 – 0,75	1,0	2.0	–

3.4. Reinforcement corrosion prediction

The time required for the development of reinforcement corrosion T_a – time is taken into account, which is necessary for the complete neutralization of the concrete protective layer (see Appendix 3.3). The function of reducing the cross-section of the reinforcement corresponds to the function of the failure in the reliability theory.

For long-term reinforced concrete structures, reinforcement corrosion can be predicted from the calculation relationship of the wear-and-tear:

$$Sc= \Delta F_a = \left(a^{i*(1-T_a)K} - 1\right) \cdot 100\% , \qquad (3.10)$$

where ΔF_a – The area of corroded reinforcement in %, determined by comparing the corroded area with the initial cross-section. It is an indicator of the corrosion function, which characterizes the corrosion rate under different operating conditions;

t – age of the structure (in years);

Tcarb – carbonization time of the protective layer of concrete;

K – accelerated corrosion growth coefficient due to external factors, which is calculated by the formula:

$$K = K_1 \cdot K_2 \cdot K_3 , \qquad (3.11)$$

K1 – coefficient determining the formation of cracks at the design stage after the manufacture of the slab K1 = 1.0;

KH – coefficient determining the quality of waterproofing K2 = 1.0;

K3 – coefficient taken according to the climatic zone (K1 = K3 during design).

The influence of cracks on the corrosion process can be determined according to the instructions of BCH 32-89 [10].

The quality of waterproofing is indicated for three conditions:

a) in the absence of defects (taken during design);

b) a single trace of leakage from concrete is observed on the cantilever surfaces of the slabs;

c) leakage is observed over the entire surface of the longitudinal seam on the monolithic slab.

Schedule 3.5

K_{crc} and K_3 – coefficient values

The crack formation coefficient Kcrc is taken according to the crack size, ; K3 – coefficient according to climatic zones.

Reinforcement types *Q* mm stretched	<0,2ðð<	0,5 ðð>	10,5ðð	north	center	south
Reinforcement on the transverse seam	1,0	1,10	1,25	1,20	1,0	0,9
(consolidation of the lower	1,0	1,1	1,25	1,5	1,2	0,9
row)	1,1	1,25	1,25	1.20	1,0	0,9
On the facade surface						
On the inner surface of the coil	1,1	1,25	1,50	1,1	1,0	0,9
On the lateral coils and						
On the slabs;	1,0	1,10	1,25	1,1	1,0	0,8
On the main reinforcement on the intermediate coils						

Schedule 3.6

K_3 - Waterproofing coefficient values

Reinforcement types			
Longitudinal seams	1,0	1,1	1,25
	1,0	1,2	1,5
Facade surfaces of edge coils			
	1,0	1,0	1,1
Intermediate coils and slabs			

At the design stage, Kbz = 1.0 and Kh = 1.0. In this case, it is possible avail the privelege of basic graph of corrosion (see Fig3.4)

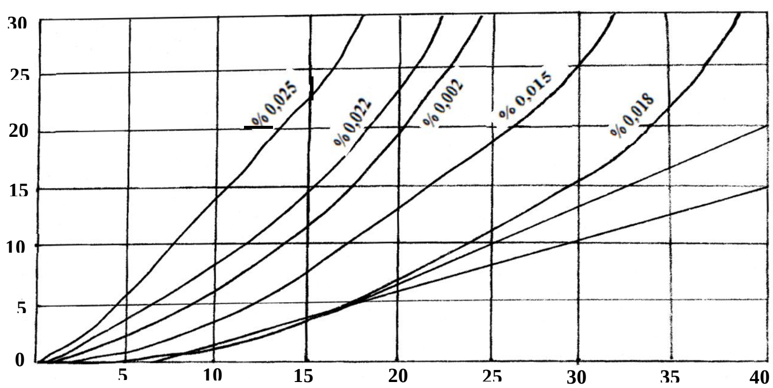


Fig. 3.4. Graph of basic reinforcement corrosion rates when Tkr=0; Kbz=Khydr.=K3 = 1.0

schedule 3.7
Baseline values for reinforcement wear
Reinforcement location

Reinforcement type	Longitudinal seams during monolithic	Facade overhangs, edged with corrugated iron panels	Intermediate Fili's mid-aled coil
Reinforced concrete product with conventional reinforcement, bottom row of main reinforcement	–	0, 0220	0,0120
Next rows	–	0,0160	0,0120
Bent rods	–	0,0160	0,0120
Straps	0,0200	0,0250	0,0150
Rebars on longitudinal joints Slab reinforcement	–	0,0200	–0,0150
Reinforced concrete products with tensioned reinforcement Lower rods, lower on the arch	–	0,0150	0,0100
Rods on the wall	–	0,0100	0,0080
Rebars on longitudinal joints	0,0200	0,0100	0,0080

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