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QUALITATIVE ANALYSIS OF OPERATIONAL STRATEGY WITH REFURBISHMENT OF METALWORKS OF ENGINEERING STRUCTURES

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Abstract. The design of engineering structures with metalwork is supposed that corresponding way of operations can support the load-bearing capacity. Because of peculiarities of engineering structures, namely, inaccessibility of a lot of nodes without application of special erection equipment, heavy labour input, etc. – such kind of operation is complicated and sometimes is not carried out. The paper deals with the problems of designing and maintenance of engineering structures with metalwork with specified longevity on the basis of the offered reference methods of principal interaction of designing and maintenance phases.

Keywords: maintenance, engineering structures with metalwork, operational strategy.

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1. Types of strategies

At wear and refurbishment of separate elements and structures there is a change of structural parameters at a time as a whole (Gorokhov 1992; Pchelnikov 2007; Klimenko 2010; Yegorov 2003). For further application in the text of the paper, there will be introduced term "operational strategy". By this term we shall basically mean clearly specified and schematically carried out maintenance of the structures. On the basis of the analysis of types of wear and refurbishment of structural elements for provision of the given longevity one can extract the following types of operational strategies (Gubanov 2013):

Strategy 1 – absence of carrying out of any repair procedures;

Strategy 2 – to repair the anti-corrosion protection without repairing load-bearing metalworks;

Strategy 3 – to carry out (to change) the load-bearing strengthening without repairing of anti-corrosion protection;

Strategy 4 – to carry out (to change) load-bearing metalworks with repairing anti-corrosion protection.

The fundamental parts of the strategies are:

1) application of load-bearing capacity storage being have in prominent parts of structural parts of constructions;
2) permanent carrying out of qualified procedures in accordance to the work schedule.

The presence of initial anti-corrosion protection is important but not compulsory condition. Schematic diagrams of constructional parameters changing in terms of load-bearing capacity for various types of strategies have been given on Figure 1, where N_{in} are initial stores of the load-bearing capacity, being started target-oriented or due to generally adopted rules of designing; $N_{\min}$ is minimal load-bearing capacity determined by various criteria of the limiting states;

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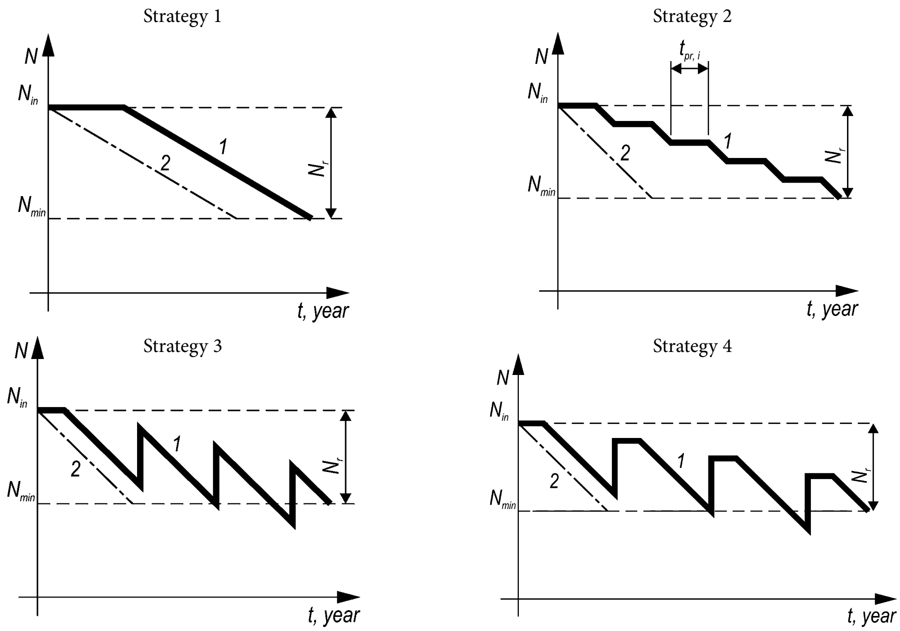

Fig. 1. Circuit design of strategies: 1 – the curve of strategy implementation; 2 – the curve of natural wear at the absence of anti-corrosion protection and without carrying out procedures of refurbishment of the load-bearing capacity

$N_r = N_{in} - N_{\min}$ is the store by load-bearing capacity. Models for strategy 4 are considered to be more detailed furthermore, as being the most complicated.

2. Strategy formalization

The provision of specified longevity at designing of constructions is based on balance-of-stores and according planning of procedures on maintenance. The operational strategies are offered to express in terms of stress, thickness and mass for this (Gubanov 2013), because:

- in the framework of design method on the limiting states, the change of the load-bearing capacity, including in time, is expressed in terms of stress;
- elements degradation in the simplest case is described by the changes of thickness;
- efficiency of adopted strategy is expressed in cost indices, which, in their term, operate on notion of mass (of an element or reinforcement).

Boundary conditions in terms of voltage and thickness can be written down in general outlook as:

$$\sigma \le R; \tag{1}$$

$$\delta \ge \delta_{\min}, \tag{2}$$

where: σ and δ is correspondingly, the stress level in the element and given thickness of the element; R is the designing strength, the value of which is taken on dependence from considered limiting state.

To get the quantitative value of cost indicators of the initial dependability level, it is necessary to carry out formalization of strategy on mass terms. Schematic description of strategies includes the following elements (Fig. 2): elements repair – vertical section, working period of refurbished protective coating – horizontal section, structural wear after the failure – inclined section. The formalization is carried out on the basis of strategic models in terms of thickness, bearing in mind linear dependence of mass from thickness and application of correction coefficients. For formalization of strategy in terms of mass is necessary:

1) to present strategy in quantitative view, convenient for making of calculation of efficiency of strategic versions;
2) to determine basic parameters of a quantitative model;
3) to take down a model in dimensionless parameters, which are convenient for practical application.

The strategy formalization in dimensionless parameters (Fig. 2) has a form:

$$p = \frac{m}{m_{\min}}, \tag{3}$$

where: m is mass or mass change corresponding to the moment or time interval of life cycle; $m_{\min}$ is minimal mass of element, when load-bearing capacity reserves are absent.

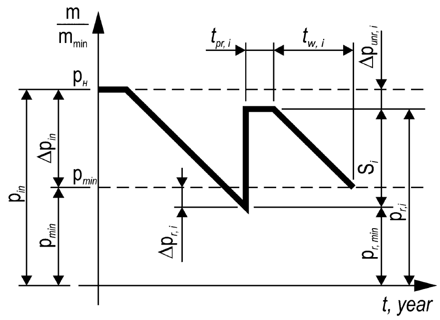

Fig. 2. Strategy formalization of operation in relative parameters

Fundamental parameters of formalized strategy in parameters are:

1) initial store on the load-bearing capacity:

$$\Delta p_{in} = p_{in} - p_{\min}, \tag{4}$$

where: $p_{in} = \dfrac{m_{in}}{m_{\min}}$ is initial store on mass, corresponding to loading-bearing capacity store;
$p_{\min} = \dfrac{m_{\min}}{m_{\min}} = 1,0$ is tolerable indicator of load-bearing capacity;

2) decrease in store of load-bearing capacity in relative parameters up to the first amplification:

$$\Delta p_i = \Delta p_{in} + \Delta p_r = \frac{m_{in,r}}{m_{\min}} + \Delta p_r = \frac{m_{in,r} + \Delta p_r\, m_{\min}}{m_{\min}}, \tag{5}$$

where: $m_{in,r}$ is mass corresponding to the initial (designing) store on load-bearing capacity; Δp_r is admissible decrease of the load-bearing capacity in comparison with tolerable to the interval of strengthening carrying out;

3) standard of increasing of the load-bearing capacity at strengthening:

$$s_i = \Delta p_i - \Delta p_{unr,i}, \tag{6}$$

where $\Delta p_{unr,i}$ is unrepairable wear;

4) the store after carrying out of strengthening will compose:

$$p_{r,i} = p_{r,\min} + s_i, \tag{7}$$

where $p_{r,\min} = p_{\min} - \Delta p_{r,i}$ corresponds to decreased values of loads up to the moment of strengthening.

The fundamental time parameters charactering the i-stage of strengthening are the following:

1) lifetime of the protective coating or conditional time, during which the damage accumulation can be neglected are $\beta_{pr} t_{pr,i}$, where coefficient β_{pr} characterizes efficiency of operation of restored protective coating;

2) lifetime in the presence of some wear rate is $t_{w,i}$; the lifetime depends on the wear rate, which is characterized by generalized wear coefficient k corresponding to the degree of external exposure to the atmosphere, technological and repairing actions:

$$t_{w,i} = s_i / k. \tag{8}$$

Thus, the repairing frequency can be determined by the equation:

$$t_i = \beta_{pr}\, t_{pr,i} + t_{w,i}. \tag{9}$$

To estimate the strategy efficiency, it is necessary to shift the above-mentioned parameters into cost indicators. The fundamental parameter permitting to make the simplest shift from the wear notion to its cost indicator is mass. Working capacity condition in terms of mass is:

$$m \geq m_{\min}, \tag{10}$$

where m is an indicator of relative mass corresponding to the determined store level on the load-bearing capacity.

The relative mass of the element on the coordinate axis does not characterize dead load of elements but changing of the element mass which is equivalent to the thickness loss (or growth of stress), i.e.:

– m is mass of the element decreasing at wear and increasing after repair execution;
– $m_{\min}$ is minimally admissible mass of the element from the conditions of load-bearing capacity provision, i.e. corresponding to the condition $\sigma = R_y$.

Correlation for elements mass necessary at determination of value of repairing work can be output on the basis of the dimensionless parameters system:

1) initial mass:

$$m_{in} = m_{\min}\, p_{in}; \tag{11}$$

2) the mass loss for execution of strengthening:

$$\Delta m_i = m_{\min}\, \Delta p_i; \tag{12}$$

3) mass of the i-strengthening:

$$m_i = \frac{m_{\min}\, s_i \cdot k_s}{\beta_i}, \tag{13}$$

where k_s is the strengthening square coefficient taking into account relationship of equivalent strengthening area to wear area; $\beta_i = 0,6...0,9$ is the amplification efficiency coefficient which will be decreased after execution of consequent repairs;

4) minimal mass of strengthening reflecting the fact of impossibility to strengthen by the elements of unrestricted thickness if the dimensions of the strengthening element are compared with dimensions of the strengthened element:

$$m_{s,\min} = \frac{\delta_{s,\min}}{\delta_{in}} m_{in}, \quad (14)$$

where δ_i is initial thickness of the element (designing or after carrying out of strengthening); $\delta_{s,\min}$ is minimal thickness of the strengthening element (is taken as equal to 5–7 mm from condition of work execution of strengthening);

5) the final mass of strengthening is determined by the equation:

$$m_{s,i} = \max\left(m_i \,; m_{s,\min} \right). \quad (15)$$

Thus, the considered operational strategy with refurbishment of its implementation in terms of a change of relative mass can be presented in the following view (Fig. 3):

– value of relative mass of the element m in unrestricted time station t:

$$m_4\left(t\right) = m_{in} - \sum \Delta m_{4,i}\left(t\right) + \sum \Delta m_{s4,i} \geq m_{\min}; \quad (16)$$

– change of relative mass at wear (at decrease of the cited thickness δ):

$$\Delta m_{4,i}\left(t\right) = k_m \Delta\delta_{4,i}\left(t\right); \quad (17)$$

– change of relative mass at repair (at increase of the cited thickness δ):

$$\Delta m_{s4,i} = f\left(\Delta\delta_{s4,i};\beta_i\right). \quad (18)$$

Practical application of any strategy can be done via its consideration from the point of view of the normal operation of the element (structure, construction) during the whole service life. The fundamental criterion of the serviceability estimate of a structure for any of above-mentioned strategies is a stress level

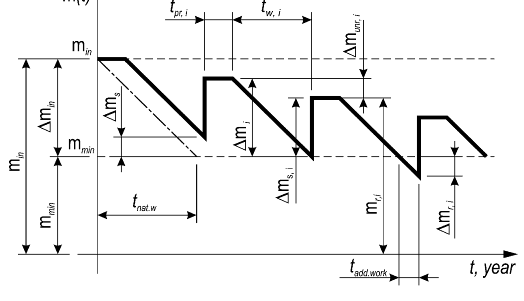

Fig. 3. Implementation of operational strategy with refurbishment in units of mass

in the element σ, which correlate with cited thickness δ. Simulation of operational strategies includes several levels:

1. Simulation of structural models of strategies representation in units of thickness and stress;
2. Simulation of schematic description in units of mass and relative parameters of mass;
3. Simulation of strategies models as piecewise continuous functions of time.

To find optimum operational strategies at provision of the required service life, it is necessary to work out cost models of effect of changing of mass indicators of works carrying out on maintenance to cost of the latest structure, which depend on periodicity and scope of activities. To reach the given purpose, it is necessary to make analysis of interaction between maintenance expenses and initial safety margin in the structural elements.

The principal criterion of efficacy in the given paper is taken the initial cost of the construction plus cost on repair and strengthening during the life cycle (Gorokhov 1992; Pchelnikov 2007; Yegorov 2002). The losses cost from downtime of production equipment, engineering, ecological and other aftereffects from possible breakdowns determined on the basis of the risks theory are not considered in the paper. Thus, taken approach determines lower borderline economically advantageous store of the load-bearing with due account of the following maintenance.

Let us consider the cost structure of the construction during the lifecycle. The cost of constructional metalworks includes the cost of a new construction C_b and the cost of maintenance C_m. With a view to consideration of wear and refurbishment during the lifecycle of a construction to the moment of building, without regard for cost of site engineering and designing, they can be presented in the form as:

$$C_b = C_{mat} + C_{man} + C_{er} + C_{pr} + C_{ma}, \quad (19)$$

where C_{mat}, C_{man}, C_{er}, C_{pr} and C_{ma} are the cost of building materials, production (manufacture), erection, anti-corrosion protection, means of access.

The cost of operation includes expenses connected with supervision of construction, performance of routine repairs and heavy overhauls and also with replacement of production equipment:

$$C_m = C_{ri} + C_{ex} + C_{pw} + C_{mcw}, \quad (20)$$

where: C_{ri} is cost of routine and extra inspections; C_{ex}

is the cost of examinations made in planned order or by the results of inspections; C_{pw} is the cost of preparatory work including the cost of working place infrastructure – ladders, cradles, installation of carrying off units and other types of erection equipment; C_{mcw} is the cost of main construction work on repair including the cost of production and erection.

The cost C_b is constant quantity depending on terms and conditions of building, process specifications and adopted reserves on the load-bearing capacity. The C_m cost is variable quantity because partially the maintenance work can be planned and taken into account, partially they depend on results of inspections and at change of service conditions they demand correction. At the same time, these two values are connected between each other adopted at designing by the reserve value on the load-bearing capacity.

The cost of the main repairing work includes the following components:

$$C_{mcw} = C_{s,pr} + \sum C_{s,i} + \sum C_{ce,j}, \qquad (21)$$

where: $C_{s,pr}$ is the refurbishment cost of anti-corrosion protection including necessary preparation of the surface; C_s is the cost of carrying-out the work and strengthening by way of increase of sections or the change of structural schematic drawing; C_{ce} is the cost of the change of secondary elements or production equipment.

The cost of strengthening or change includes except the cost of the main building materials also $C_{s,man}$, the cost of production and $C_{s,er}$, the cost of the erection (strengthening).

One of the important indicators both for the modern building and at operation of the building structures are the relative cost indicators for the element. The cost of the refurbishment processes is connected with mass of the element permitting to attach the costs of production and erection to the mass of the separate element by application of conversion factor. Let us introduce the following system of the factors:

1) $k_{r,c}$ is the design notion of the increase of the cost ($k_{r,c} > 1$) corresponding to the store on the load-bearing capacity and thickness:

$$k_{r,c} = \frac{C_{el}}{C_0}, \qquad (22)$$

where C_{el} and C_0 are the costs of the element with application and without application of the reserve factor;

2) k_b is relation of the production cost C_{man} and erection C_{er} to the cost of the element material C_{mat} at the building of the object:

$$k_b = \frac{C_{man} + C_{er}}{C_{mat}}; \qquad (23)$$

3) $k_{s,man,i}$ is for i-element relation of the cost of production $C_{s,man}$ to the cost of the element material $C_{s,mat}$ at the repair of the object;

4) $k_{s,er,i}$ is for the i-element relation of the cost of the erection $C_{s,er}$ to the cost of the element material $C_{s,mat}$ at the repair of the object (regardless the installation of means of access).

Reserve factor does not minimize mass loss of elements during specified service life. Efficiency of its usage is stipulated by the following motives:

- the more the reserve value, the less the number of repairs need to be done and greater interval of time between them;
- the less number of repairs, the less value of indirect costs connected with the appliance of means of access and erection equipment;
- the greater value of safety factor corresponds the greater reliability factor required at valid ambiguities of wear velocity.

Thus, the costs of the latest element and repairing of the element, taking into first approximation linear dependence of building cost from the mass (apart from the value of the last-mentioned), you can write down in the following view:

$$C_b = C_{mat} + C_{mat}k_b = C_0 k_r \left(1 + k_b\right); \qquad (24)$$

$$C_s = C_{s,mat} + C_{s,mat}k_{s,man} + C_{s,mat}k_{s,er} + C_{sw} =$$
$$C_{s,mat}\left(1 + k_{s,man} + k_{s,er}\right) + C_{sw}, \qquad (25)$$

where C_{sw} is the cost of supplementary work, the cost of means of access, protection from factors of danger, devices of shelters for proper equipment, etc.

The total cost of the structural element C incorporates both costs and is determined by the equation:

$$C = C_b + C_s. \qquad (26)$$

Probably, the most rational is the case when the total cost of the structure is minimal, i.e. $C = C_b + C_s \rightarrow \min$. Taking as basic value for structural cost of the element without application of the safety factor C_0, condition of optimality by the cost can be written down as:

$$C = \frac{C_r + C_s}{C_0} \rightarrow \min, \qquad (27)$$

where C_r is the cost by the bearing capacity factor:

$$C_r = C_0\left(k_r - 1\right)\left(1 + k_b\right). \quad (28)$$

The given condition can be also represented in terms of relative mass *m*:

$$C_r = m_0 k_{c,0}\left(k_r - 1\right)\left(1 + k_b\right); \quad (29)$$

$$C_s = \sum_{i=1}^{n}\left(m_{s,i} k_{c,s,i}\left[1 + k_{s,man,i} + k_{s,er,i}\right] + C_{sw,i}\right); \quad (30)$$

$$C_0 = m_0 k_{c,0}, \quad (31)$$

where: m_0 is relative mass of the element at building without reserve (initial mass of the element without reserve); $k_{c,0}$ is the mass unit cost of the element at building; $m_{s,i}$ is the relative mass at i-type repair; $k_{c,s,i}$ is the mass unit cost at i-type repair.

The presented-above formulas of the value indicators are determined for the level of local strengthening of separate elements. In case of performance of the total strengthening the decrease of stress level to the value $\Delta\sigma$ takes place. The given stress decrease corresponds to some estimated cost of work performance which can be represented as voltage decrease function. The function mode and coefficients being among it should be determined on the base of variant cost accounting of the work for various types of high-rise structures. The linear dependence can be taken at first approximation. In general view, the total strengthening cost is determined as:

$$C_{s,t} = c_\sigma \Delta\sigma_s, \quad (32)$$

where: $\Delta\sigma_s$ is required voltage decrease at amplification; $c_\sigma = \frac{C_s}{\Delta\sigma_q}$ is the cost indicator; C_s is the cost of strengthening corresponding to voltage modification $\Delta\sigma_q$ and determined on the basis of estimated calculation.

To estimate the efficiency of made decision about value of reserve coefficient on bearing capacity it is necessary to make summing-up of expenses to the building with operating costs. Since building and repair are made in various periods, it is necessary to apply economic methods for bringing the costs taking place at different time to the unified moment of time. Since the building and repair are made at different time, it is necessary to apply Application of the following methods is possible:

1. Putting to the nowadays cost. In this case In this case nowadays expense cost $C_{s,t}$, made in *t* years are:

$$C_{red} = \frac{C_{s,t}}{\left(1 + \alpha\right)^t}, \quad (33)$$

where α is a coefficient of putting of costs taking place at different time or a coefficient of value discounting is in the limits of 0.08–0.15 and can be determined both by macroeconomic processes and by the indicators of profit level adopted on the exact enterprise.

Of special interest is the approach is used for the investment decisions taking as the basis, therefore it does not consider expenses of a structure owner bearing costs during the whole service life.

2. Annual cost method. In this case, the initial cost of a structure is driven to the annual value by equation:

$$C_{b,year} = C_b\left(\frac{\alpha\left(1 + \alpha\right)^{T_{sl}}}{\left(1 + \alpha\right)^{T_{sl}} - 1}\right), \quad (34)$$

where T_{sl} is the prescribed service life.

Cost of maintenance work given to the annual costs is added to the value:

$$C_{year} = C_{b,year} + \frac{\sum C_{s,t,i}}{T_{sl}}, \quad (35)$$

where $C_{s,t,i}$ is components of maintenance costs.

3. Strategy implementation at design

Application of the strategies to determine optimum version of service is made by usage of optimizing method of reliability by comparison of the finite types of versions by direct sorting. Discrete nature of transient parameters of work execution having limitation to the cycle number because of internal peculiarities of amplification processes and repair is responsible for it. Strategy implementation is realized on the basis of algorithm, which includes the following components:

1. Modification of section thickness is used for description of generalized wear in time in form of linear process. Stress change in time is more complicated since type of checks by limiting states affect on voltage dependence from the element thickness.
2. Time, when it is necessary to make repair, is determined on the corresponding minimal thickness of the thickness change.
3. Reduces mass of elements is determined by reduced thickness.
4. The version costs are determined by reduced mass or on the basis of dependences between cost and stress at application of total strengthening.

Let us imagine strategy services in form of sectionally continuous functions from time with the point of account at the moment of building completion and putting into operation. To do it, let us define all the necessary for it variables and functions. The function period composes:

$$\Delta t_{c,i} = t_{k,i} - t_{n,i}, \tag{36}$$

where: $t_{k,i}$ is the end of the cycle "repair-wear"; $t_{n,i}$ is the beginning of the cycle.

The cycle is the cum of components corresponding to the absence of wear $\Delta t_{pr,i}$ and the presence of wear $\Delta t_{w,i}$:

$$\Delta t_{c,i} = \Delta t_{pr,i} + \Delta t_{w,i}. \tag{37}$$

Furthermore, the symbol Δt in these formulae means that temporary characteristics are relative to the separate cycle but not to the operation time. Service life of protective covers is taken depending from durability of protective system $T_{pr,in}$:

$$\Delta t_{pr,i} = \begin{cases} T_{pr,in}, & \text{if} \quad i = 1 \\ \beta_{pr} t_{pr}, & \text{if} \quad i = 2 \ldots n. \end{cases} \tag{38}$$

The possible wear duration for separate maintenance cycle can be determined by two versions depending on the record-keeping of inherent wear. If inherent wear is evaluated in terms of thickness, then:

$$\Delta t_{w,i} = \frac{\Delta\delta_{r,i} - \delta_{\min} - \Delta\delta_{unr}(i-1)}{k}, \tag{39}$$

where: $\Delta\delta_{r,i} = f(\Delta\sigma_r)$ is the reserve on the bearing capability in thickness units regardless to inherent wear; $\Delta\sigma_r$ is the initial reserve of the bearing capacity in stress units; $\Delta\delta_{\min} = f(R_r)$ is minimally admissible thickness as a function of borderline meaning of strength; k is velocity of extended wear.

If inherent wear is evaluated in stress units, that is more generalized case, then duration of wear in the service cycle is determined by equation:

$$\Delta t_{w,i} = \frac{\Delta\delta_{r,in,i} - \delta_{\min}}{k}, \tag{40}$$

where: $\Delta\delta_{r,in,i} = f(\Delta\sigma_{r,in})$ is the reserve on the bearing capacity in thickness units with regard to inherent wear; $\Delta\sigma_{r,in} = f(R; k_{r,in})$ is the initial reserve of the bearing capacity in stress units; $k_{r,in}$ is the reserve coefficient with regard to inherent wear.

The end and the start of each service cycle from the operation from the operation start-up are determined by equations:

$$t_{n,i} = \sum_{j=1}^{j=i} \Delta t_{c,j} - \Delta t_{c,i}; \quad t_{k,i} = \sum_{j=1}^{j=i} \Delta t_{c,j}. \tag{41}$$

The number of maintenance cycles is determined iteratively as maximal value of n, under which condition of provision of prescribed service life is carried out:

$$\sum_{1}^{n} \Delta t_{c,i} \le T_{sl}, \tag{42}$$

where T_{sl} is prescribed service life of an element.

Using determined above values, you can evaluate the change thickness in time in form of the sectionally continuous function.

$$\Delta\delta(t) = \begin{cases} 0, \text{ if } t_{n,i} \le t < t_{n,i} + \Delta t_{pr,i} \\ -k\left(t - \Delta t_{pr,1}\right), \text{ if } t_{n,i} + \Delta t_{pr,1} \le t < t_{k,1} \\ \Delta\delta_{s,i}\,\beta_i - k\left(t - t_{n,i} - \Delta t_{pr,i}\right) \\ \qquad \text{if } t_{n,i} + \Delta t_{pr,i} \le t < t_{k,i},\ i > 2 \end{cases}. \tag{43}$$

The next step for strategy implementation is thickness expression via stress with regard of the initial reserves of the bearing capacity. The form of such dependences is determined by the check types of the bearing capacity within the limit state design method.

The result of strategy utilization is:

- optimum value of the reserve coefficient on the initial bearing capacity;
- the repair schedule on the basis of wear parameters, characteristics of strengthening and initial level of design reliability.

4. Strategy analysis

Having realized above-mentioned statements for particular object, one can carry out strategy analysis for structural elements. The given analysis was made on the example of the lattice tall structures with the following initial parameters:

- period of operation is 40 years;
- period of protective roof service life is 5 years;
- efficiency ratio of protective roof (at repeated coating) is 0.8;
- design thickness of an element is δ_0 =12mm;
- minimally admissible thickness of an element is 8mm;
- minimal thickness of strengthening is 5mm;
- wear velocity is $k_w = 0{,}02 \cdot \delta_0$;
- inherent wear is $0{,}4 \cdot k_w$;
- time of protection repair is 0,1 from the design period of roof life;
- cost at building:
  - building material is 12 units;

- manufacturing is 12 units;
- erection – 7 units;
- cost at repair:
  - building material is 6 units;
  - manufacturing is 2 units;
  - erection is 1 unit;
  - access devices (in shares from erection value) is 1;
  - refurbishment of protective roof is 15 units.

The analysis of proposed strategies starts with the research of dependence change of repair cost from the value of reserve coefficient (Fig. 4). Initially obtained dependence does not correspond to the generally accepted ideas of the character of expenses changes to repairs at increase of initial structural reserve. But at consideration of obtained dependence together with schedule of the change of amount of necessary repairs at the same initial conditions, their interaction is traced – there are misunderstood initially vertical jumps occur at the change of repairs amount. Thus, depending from the cost of repairs amount one can single out a standard block or unit given in Fig. 5a. For similar initial conditions, a magnitude ΔC_i has similar value for all the jumps of a schedule, but a magnitude Δkr_i is changed with increase of the reserve coefficient value. If a jump-like change becomes apparent at the change of repairs amount, so increase of repairs cost in the limits one and the same number of them is shown in Fig. 5b. In this case the cost increase occurs in consequence of mass increase of repair metal.

Thus, one can speak about the fact, that at any precisely determined initial data, increase of the reserve coefficient does not decrease repairs cost without fail. One can single out a finite number of value intervals of the reserve coefficient which give the cost minimum repairing measures. Deviation from these exponents means leaving from the cost minimum at the same number of repairs.

But the given dependence is not the single determining criteria of the strategy choice because at equal repairs amount, increase of the reserve coefficient causes increase of object service life (Fig. 6).

Respectively, the strategy choice by the cost criteria practically at the first stage transits into solution

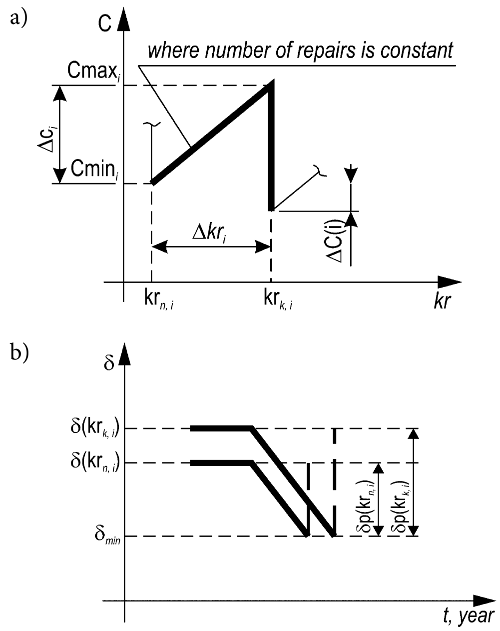

Fig. 5. Cyclically repeated structural units of dependence of repairing cost and repair amount from the reserve coefficient: a – general view of a structural unit of repairing cost dependence from the reserve coefficient dependence; b – cost change (mass, thickness) of repair metal in the limits of one and the same repair amount

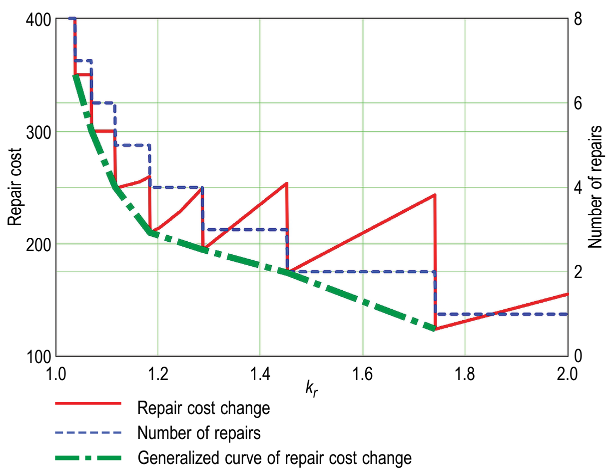

Fig. 4. Dependence of repairing cost and repair amount from the reserve coefficient

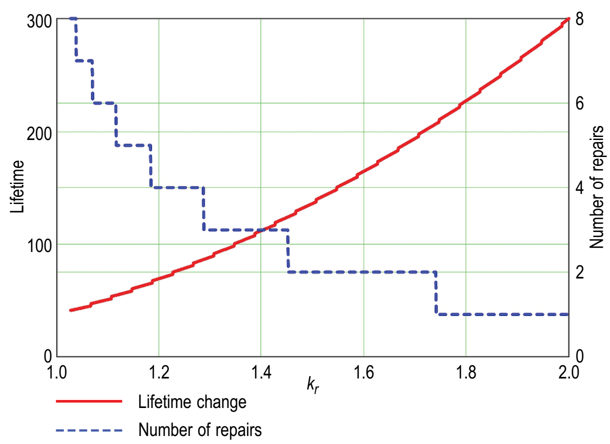

Fig. 6. Dependence of service life and repairs amount from k_r

of the problem with three variables: repairs amount, required service life and necessary reserve coefficient.

Strategy efficiency is determined by design purpose:

1. Minimization of building cost is for a tenant carrying out building with a view to re-sale in the future (i.e. who is not going deal with service of a building after construction).
2. For "pure operational" organization is minimization of costs to repair during the determined period of time. The value of the period is determined individually in each case but always includes into itself just only repairing cost.
3. Minimization of expenses to repair and construction is for organization deals with construction and maintenance during the definite period of time.
4. Since the approach offered in the paper is directed mainly to the research of the complete cycle of structural service life including construction and consequent operation, so only the third version is subjected to consideration.

Let us determine the relation of amount of expenses to the reserve provision at construction and repairing cost to the "base" construction cost as the target-oriented function. In the rest of fixed data, the dependence of the given factor from the reserve coefficient for various service strategies is given on the Fig. 7. Let us also plot dependence "repairs amount – reserve coefficient" on the given schedules.

The general profile of the schedule corresponds to Fig. 4, i.e. determined repairs amount corresponds to its own dependence which has a linear view and minimal value for precise repairs amount in the point with minimal value of the reserve coefficient. External view of the given dependence repeats for values of magnitudes values prescribed in the capacity of affecting factors.

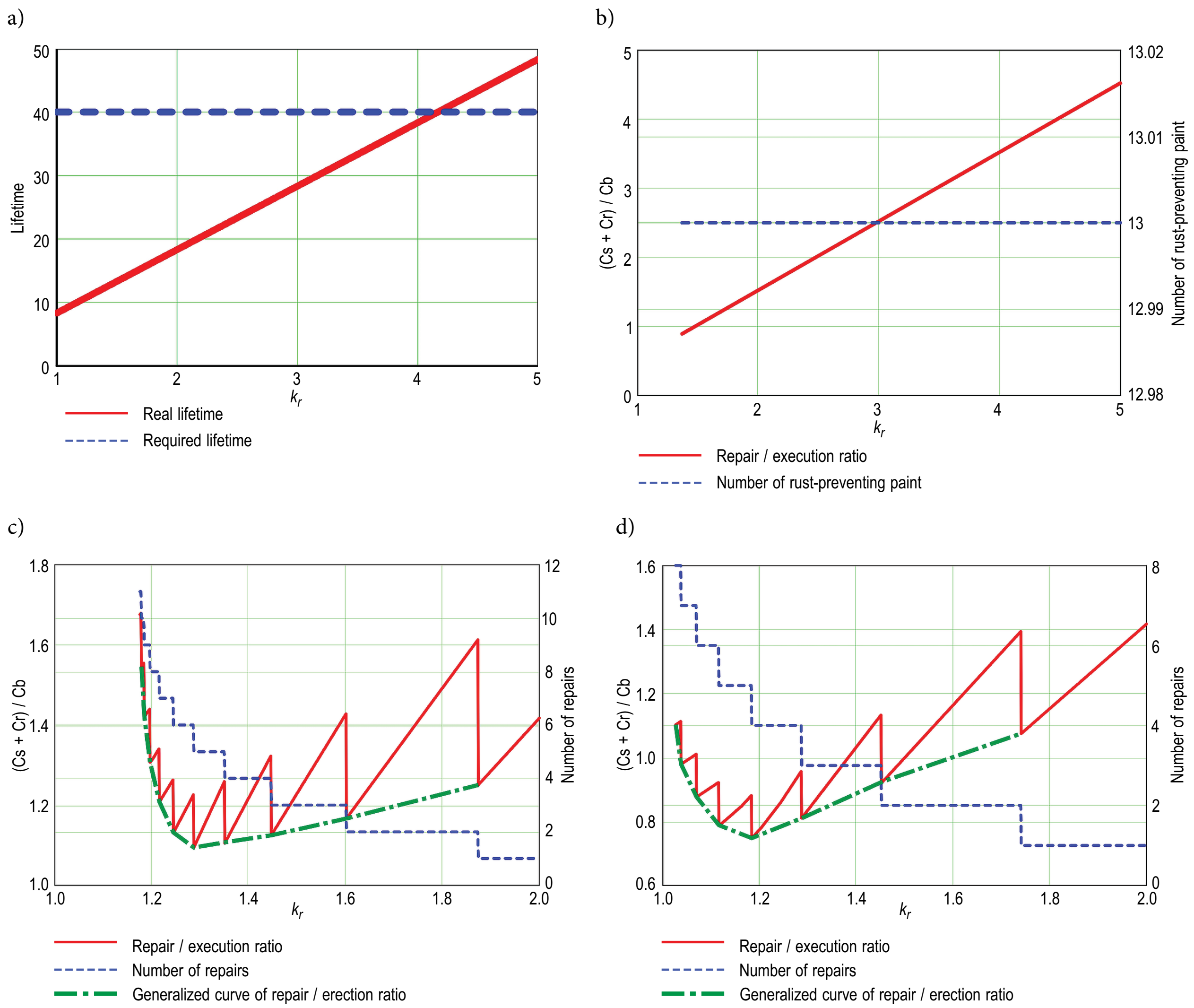

Fig. 7. Dependence of costs to reserve and repairs provision to the "base" construction cost from the reserve coefficient: a – the first strategy; b – the second strategy; c – the third strategy; d – the fourth strategy

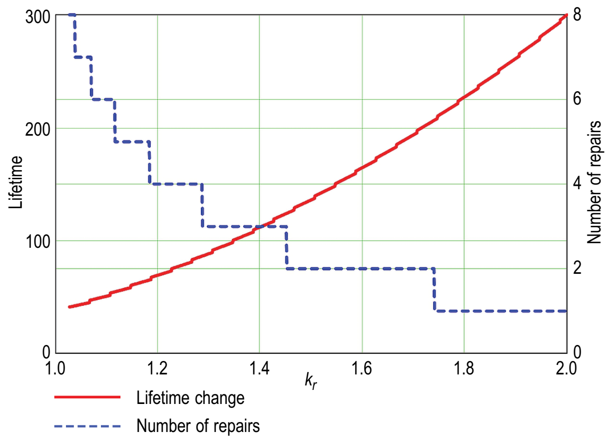

Fig. 8. Dependence of relation of sums given to reserve provision at construction and repairing cost to the "base" construction and repairs amount from the reserve coefficient

From the point of view of adjusted expenditures (Fig. 8), general situation of the sharp change of the function at repairs amount change repeats, in this case the minimum is at the reserve coefficient equals to 1, i.e. this is actually an efficiency with respect to the strategy 1 version.

Principal conclusions

1. The change of repairing cost depending on accepted reserve coefficient occurs jump-like in consequence of necessary repairs amount change (representing integers). The general tendency of decrease of repairing cost at increase of reserve coefficient is observed.
2. In limits of the same repairs amount, the local minimum of cost is observed at minimal value of the reserve coefficient by means of decrease of upper lath of thickness (mass) reached at repair execution.
3. Determination of optimum value of the reserve coefficient (and amount of necessary repairs) at given initial data is possible by research of relative cost change dependence and repairs amount from the reserve coefficient.
4. The strategy selection depends on opportunity, necessity and desire to carry out consequent repairs of an object:
   - at impossibility or absence of intention to support working capacity state of an object to repair, it is necessary to use the first strategy;
   - in case of necessity of initial resources saving (to construction) and planning to carry out repairs of a structure in future, it is necessary to make choice of 2nd, 3rd and 4th strategies; the final choice of one from the three strategies depends on the exact cost indicators of execution of work on the corrosion protection refurbishment and strengthening.

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