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EXPOSURE OF THE LOAD CAPACITY OF THE RC STRUCTURAL SYSTEM UNDER CORROSION DAMAGE TO COLUMNS

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A number of accidents, such as the partial collapse of a residential building in Surfside on June 24, 2021, or the collapse of the roof structure of Basmanny Market in Moscow on February 23, 2006, show that aggressive medium impacts on reinforced concrete structures lead over time to a decrease in their strength resistance resource under accidental impacts. At the same time, the investigations in this field mainly deal with structural members under bending, while eccentrically compressed and corroded reinforced concrete members have been considered either in particular aspects or the obtained solutions are rather complicated for their practical application. In this regard, the purpose of the article was to assess the influence of the corroded depth on the load capacity of eccentrically compressed reinforced concrete columns of structural frames, as well as to predict the time of exhaustion of their load capacity under constant serviceable loads. The paper adopted the phenomenological model of V.M. Bondarenko to take into account long-term corrosion processes. It had been established that an increase in the corroded depth leads to a decrease in the load capacity of eccentrically compressed reinforced concrete members due to a decrease in the effective cross-sectional depth and effective slenderness ratio. The relative depth of the destroyed concrete varies depending on the current stress-strain state of the structural member. The time to reach the critical corroded depth depends significantly on the parameters of aggressive medium and the stress-strain state of the structural member and may differ by several times when implementing avalanche or descending damage kinetics.

Keywords: reinforced concrete, column, corrosion, robustness, exposure

1 INTRODUCTION

Structural frames of facilities are subject to the action both of force and environmental impacts during their service life. The environmental impacts may include exposure to high or extremely low temperatures, contact with aggressive medium. Environmental impacts can lead to degradation of the mechanical properties of concrete and steel reinforcement. Also, it decreases bond strength between the reinforcement and concrete. As a result, structural members loss their load capacity that leads to the complete or partial collapse of the facility, such as the Surfside condominium partial collapse (Florida, USA) on June 24, 2021 [1] or the Basmanny Market roof collapse (Moscow, Russia) on February 23, 2006 [2]. In this regard, an urgent problem is the prediction of changes in the robustness of reinforced concrete structural systems during the evolutionary accumulation of corrosion damages in them.

The investigations of robustness of the reinforced concrete structural elements contacting with aggressive medium can be conditionally separated into two groups: a) studies of the degradation processes in concrete under various types and concentrations of aggressive medium, the shape and size of samples, stress-strain state, etc., b) studies of the effect of corrosion damage of longitudinal and transverse reinforcement on the resistance of structural members.

The first group includes the work of Xiao et al. [3], in which the authors present the results of an experimental study of the effect of sulfuric acid on the change in the stress-strain state of concrete specimens under uniaxial compression. They established a decrease in compressive strength by 32% and an elasticity modulus by 15% for 250 days of exposure in an aggressive environment. Zhou et al. [4] investigated deterioration of concrete fracture toughness and elastic modulus under acid-sulfate environment. Authors established a relationship between the parameters of an aggressive environment and the depth of corrosion damage over time. Depending on the pH-parameter of the medium, the rate of corrosion damage can vary significantly, reaching a maximum at pH = 1.5 among the considered options. Yang et al. [5] presented a study of a stress-strain constitutive model of concrete in a saline soil environment. Their article provides diagrams obtained for specimens after 5, 10, 15 and 20 months of exposure to the environment. Despite a temporary increase in strength during exposure from 5 to 15 months, with a longer period of contact with an aggressive environment, a decrease in strength and elasticity modulus were observed. Wen et al. [6] present the results of a nonlinear numerical simulation of the degradation of reinforced concrete beam under chloride ion corrosion. On the basis of simulation, a sharp decrease in the stiffness of a 2-span reinforced concrete T-beam was revealed after 30 years from the beginning of the contact with an aggressive environment. This led to a multiple increase in the deflection of the beam structure.

Based on experimental data on the resistance of reinforced concrete elements under the influence of aggressive media, Bondareko et al. [7] and Selyaev et al. [8] proposed phenomenological degradation functions that allow modeling the deformation of reinforced concrete elements damaged with corrosion. Such degradation functions allow estimation of the residual life of structures.

The second group of works includes studies of issues related to the processes at the interface between reinforcement and concrete during corrosion damage to steel reinforcement, as well as the influence of these processes on the bearing capacity of structural elements. Smolyago et al. [9] investigated the influence of defects in reinforced concrete structures on the corrosion damage of reinforcement. Based on the monitoring data for long-term exploited buildings and structures, the authors concluded that one of the most common types of damage to reinforced concrete structures is corrosion damage to reinforcement, followed by cracking and peeling of the protective layer. Developing these conclusions, Tamrazyan et al. [10], [11] studied the resistance of compressed reinforced concrete elements in the event of loss of adhesion between steel reinforcement and concrete in local areas. It was found that corrosion damage leads to a change in the distribution of stresses through the cross sections and, as a result, the depth of the compressed concrete changes. Liu et al. [12] considered the combined effect of corrosion and strain rate on bond strength. The authors noted a rapid decrease in adhesion at initial levels of corrosion damage. After that, the bond strength stabilizes and remains unchanged as the level of corrosion damage increases. Ma et al. [13] investigated the effect of corrosion damage to transverse reinforcement on the resistance of confined concrete. The decrease in the bearing capacity of the elements is shown depending on the different level of corrosion damage from 0 to 27%. Jeon et al. [14] presented a model of prestressed cable reinforcement of a reinforced concrete structure, taking into account corrosion damage. They provided dependences for reduction of the effective strength of reinforcement.

It is appropriate to note that the degradation of concrete and corrosion of reinforcing steel, as a rule, occur simultaneously. Thus, it should be accounted jointly when assessing the exposure of the structural system robustness, following the terminology of Bondarenko [15].

Since the large number of factors effects on the development of non-equilibrium corrosion processes in reinforced concrete structural members exposed to aggressive medium, as well as the they are of largely random nature over time. Tamrazyan et al. [16] considered the resistance of reinforced concrete elements damaged with corrosion from the point of view of risk assessment. They provided proposals for optimizing design solutions, taking into account the acquisition of defects and corrosion damage.

The publications in this field mainly cover the issues of load capacity of reinforced concrete structural members under bending. In addition to the works discussed above, the studies of Li et al. [17] and He et al. [18] should be noted as it devoted to the bearing capacity of reinforced concrete beams subject to corrosion. Thus, the assessment of the resistance of compressed members is a complex problem, which includes the influence of the second order effects, changes in stiffness and force eccentricity over time due to the accumulation of corrosion damage. Therefore, the corroded eccentrically compressed reinforced concrete members have been considered either in some particular aspects [10, 11] or the obtained solutions are rather complicated for their practical application [15].

In this regard, the purpose of the presented study was to assess the influence of the cross-sectional corroded depth of eccentrically compressed reinforced concrete columns on the load capacity of facility structural frame, as well as to predict its robustness exposure, i.e., the time of exhaustion of the bearing capacity under serviceable loading and contact with aggressive medium.

2 METHOD

This study consisted of two parts. The first part included the construction of analytical expressions for the N-M interaction curves that determine the bearing capacity of eccentrically compressed reinforced concrete elements subject to corrosion. The second part of the study involved numerical simulation of the deformation of eccentrically compressed reinforced concrete elements under certain parameters of load, slenderness, and corrosion damage depth.

To simulate non-equilibrium processes of corrosion damage, the phenomenological model of Bondarenko [7] was adopted, the parameters of which are determined on the basis of empirical data:

$$\delta(t,t_0)=\delta(\infty,t_0)\left\{1-\left[\alpha(1-m)(t-t_0)+\left(1-\frac{\delta(t_0,t_0)}{\delta(\infty,t_0)}\right)^{1-m}\right]^{\frac{1}{1-m}}\right\}, \qquad (1)$$

where t, t_0 are the current and initial observation time; $\delta(\infty,t_0)$ is the ultimate value of the corroded cross-sectional depth at fixed aggressive medium parameters, material, form and size of the structure, as well as its stress-strain state; $\delta(t_0,t_0)$ is the corroded cross-sectional depth at initial observation time. If the aggressive medium begins to act on the structure at initial time, then $\delta(t_0,t_0)=0$. α, m are the empirical parameters of eq. (3) depending on kinetics parameters.

To find the time until the bearing capacity of a compressed reinforced concrete element damaged with corrosion will be exhausted, the inverse problem should be solved. First, the critical value of the corroded depth is determined, at which the loss of bearing capacity occurs. Then, from eq. (1), it follows the time t_{cr} corresponding to reaching the critical value of the corroded depth and consequently the exhaustion of the bearing capacity of structural member:

$$t_{cr}-t_0=\frac{1}{\alpha(1-m)}\left[\left(1-\frac{\delta_{cr}(t_{cr},t_0)}{\delta(\infty,t_0)}\right)^{1-m}-\left(1-\frac{\delta(t_0,t_0)}{\delta(\infty,t_0)}\right)^{1-m}\right]. \qquad (2)$$

The critical time value t_{cr} allows to evaluate the change in the robustness parameters of the facility operated under conditions of simultaneous manifestation of factors of force and environmental influences, as well as taking into account accidental impacts.

Fig. 1, a presents scheme of an eccentrically compressed reinforced concrete column of rectangular cross section exposed to an aggressive medium along all four faces. The hypothesis of the constancy of the ratio between the mechanical parameters of corrosion-damaged and undamaged concrete [7] was adopted, as follows:

$$\frac{f_{c(ct)}^{cor}(t)}{f_{c(ct)}}=\frac{E_c^{cor}(t)}{E_c}=\frac{\varepsilon_{cu(ctu)}^{cor}(t)}{\varepsilon_{cu(ctu)}},$$

where $f_{c(ct)}$, E_c, $\varepsilon_{cu(ctu)}$ are the compressive (tensile) strength of the undamaged concrete, tangent modulus of elasticity of normal weight undamaged concrete at a stress of $\sigma_c = 0$ and at 28 days, ultimate compressive (tensile) strain in the undamaged concrete; $f_{c(ct)}^{cor}(t)$, $E_c^{cor}(t)$, $\varepsilon_{cu(ctu)}^{cor}(t)$ are the same values for the concrete exposed in aggressive medium during time *t*.

To describe the change in the parameters of the material strength along the corroded depth of the concrete cross section, an empirically established degradation function (Fig. 1, b) [7] has been adopted:

$$K(z)=\sum_{0}^{2}a_i z^i.$$

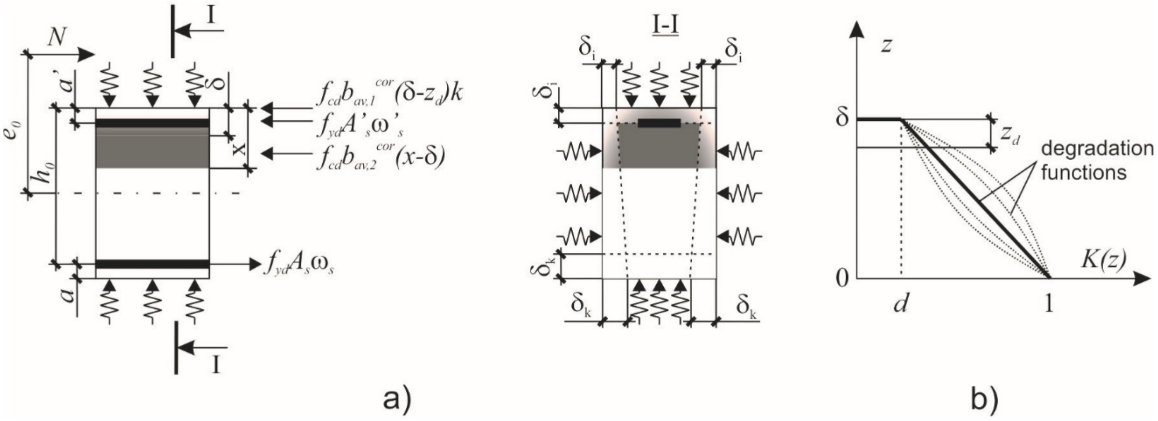


Fig. 1. Scheme for the structural analysis of an eccentrically compressed corrosion-damaged reinforced concrete column (a), a general view of the degradation functions for the corroded concrete [7]

For the above-mentioned hypotheses and assumptions, the load capacity of an eccentrically compressed corroded reinforced concrete column is determined by the formulas:

- for x≥ δ:

$$\begin{aligned}(N\cdot e_0\cdot\eta)_{ult}&=f_{cd}\\&\cdot\Big[b_{av,1}^{cor}\cdot(\delta-z_d)\cdot k\cdot(h_0-\delta+z_{g.c.,1})+b_{av,2}^{cor}\\&\cdot(x-\delta)\left(h_0-\frac{x+\delta}{2}\right)\Big]+\left(f_{yd}\cdot A_s^{'}\cdot\omega_s^{'}-\frac{N}{2}\right)(h_0-a^{'}),\end{aligned} \qquad (3)$$

- for x< δ:

$$\begin{aligned}(N\cdot e_0\cdot\eta)_{ult} = {} & f_{cd}\cdot b^{cor}_{av,1}\cdot(x-z_d)\cdot k\cdot\left(h_0-x+z_{g.c.,1}\right)\\ & +\left(f_{yd}\cdot A'_s\cdot\omega'_s-\frac{N}{2}\right)\left(h_0-a'\right).\end{aligned} \tag{4}$$

We adopted the following designations in the formulas (1), (2): $\eta = 1/\left(1-\frac{N}{N_{cr}}\right)$ is the moment magnification factor that accounts action of a second order moment;

N, N_{cr} are the calculated axial load and a critical value of the axial load at stability failure in pure axial;

f_{cd}, f_{yd} are the design values of concrete compressive strength and design yield strength of reinforcement;

A_s, A'_s are the cross-sectional area of the reinforcement in tension and compression respectively;

h_0 is the effective cross-sectional depth of the reinforced concrete member;

δ is the corroded cross-sectional depth;

ω_s, ω'_s are the reinforcement strength decreasing factors, which account decreasing of the effective reinforcement cross-sectional area and descending of the bond strength due to corrosion damage;

$b^{cor}_{av,1}$, $b^{cor}_{av,2}$ are the average effective cross-sectional width along the corroded depth δ and from δ to (*x* – δ) respectively, which should be determined from the formula:

$$b^{cor}_{av,1(2)} = b - 2\delta_{i(k)}\left(1-\frac{1}{\delta_{i(k)}}\int_0^{\delta_{i(k)}} K(z)dz\right);$$

k is the factor reducing cross-sectional area of the corroded concrete to effective one, as follows:

$$k = \frac{1}{\delta - z_d}\int_0^{\delta - z_d} K(z)dz\,;$$

x is the effective depth of compressed area of the member’s cross section, which is determined from the following formulas:

- for $x \le x_R$:

$$x = \delta + \frac{N + f_{yd}\cdot A_s\cdot\omega_s - f_{yd}\cdot A'_s\cdot\omega'_s - f_{cd}\cdot b^{cor}_{av,1}\cdot(\delta - z_d)\cdot k}{f_{cd}\cdot b^{cor}_{av,2}},$$

- for $x > x_R$:

$$x = \delta + \frac{N + f_{yd}\cdot A_s\cdot\omega_s\cdot\frac{1+\xi_R}{1-\xi_R} - f_{yd}\cdot A'_s\cdot\omega'_s - f_{cd}\cdot b^{cor}_{av,1}\cdot(\delta - z_d)\cdot k}{f_{cd}\cdot b^{cor}_{av,2} + \frac{2\cdot f_{yd}\cdot A_s\cdot\omega_s}{h_0\cdot(1-\xi_R)}},$$

z_d is the conventionally destroyed cross-sectional depth, for which the condition $\varepsilon_c \le \varepsilon_{cu}\cdot K(z_d)$ is not satisfied.

The limiting value of the compressed area depth x_R of the corrosion-damaged reinforced concrete cross-section at a two-line approximation of the stress-strain curve is as follows:

$$x_R = \xi_R h_0 = \frac{\alpha\left(h_0 - z_d\right)}{1 + \frac{\varepsilon_{s,el}}{\varepsilon_{cu}K\left(z_d\right)}},$$

where parameter α depends on the strain value at the corroded cross-sectional depth δ:

- for $\varepsilon(\delta) > \varepsilon_{c1,red}$:

$$\alpha = 1 - \frac{\varepsilon_{c1,red}}{2\cdot\varepsilon_{cu}K(z_d)},$$

- for $(\delta) \le \varepsilon_{c1,red}$ $\alpha = 0.5$.

To calculate critical force, the effective stiffness of the reinforced concrete cross section damaged by corrosion can be determined as follows:

$$B_{red,cor} = k_c \cdot E_c \cdot \int_{-\frac{h}{2}-z_{g.c.}}^{\frac{h}{2}-z_{g.c.}} b(z) \cdot K(z) \cdot z^2 dz + k_s \cdot E_s \cdot \left(A_s \cdot \omega_s \cdot \left(\frac{h}{2} + z_{g.c.} - a \right)^2 + A'_s \cdot \omega'_s \cdot \left(\frac{h}{2} - z_{g.c.} - a' \right)^2 \right),$$

where k_c, k_s are the factors, which account nonlinear behavior of concrete and violation of concrete to steel reinforcement cohesion in accordance with [19], [20];

$z_{g.c.}$ is the displacement of the geometric center of gravity of a corrosion-damaged cross section about the center of gravity of the same cross section not exposed to an aggressive medium. The displacement of the geometric center of gravity $z_{g.c.}$ leads to an increase in the eccentricity of the application of the longitudinal force, therefore it should be added to the calculated eccentricity obtained for the column without corrosion damage.

As the second part of the study, numerical simulation of the deformation of reinforced concrete columns damaged with corrosion was performed using the finite element method. The problem was solved considering physical and geometrical nonlinearity. Exponential approximations of the piecewise linear stress-strain diagram for concrete were accepted. For steel reinforcement, a piecewise linear diagram was adopted. For a simplified account of the effect of creep on the deformed state of the elements, the effective elasticity modulus of concrete was calculated by the formula:

$$E = \frac{E_c}{(1 + \varphi_{cr})},$$

where E_c is the tangent modulus of elasticity of concrete at a stress σ = 0 and at 28 days,

φ_{cr} is the final value of creep coefficient, which was adopted in this study as $\varphi_{cr} = 3$ for the first approximation.

Based on a preliminary analysis of the mesh sensitivity of computational models, the columns were separated along the length by at least 20 FE of the beam type. A corrosion damage zone of 0.36 m length was assigned in the middle part of the column. It was simulated layer by layer as Fig. 2 shows. The finite elements of the beam type, simulating the layers of concrete and reinforced concrete in the zone of corrosion damage, were connected to the finite elements of the undamaged part of the column using absolutely rigid connecting elements. This ensured the fulfillment of the Bernoulli hypothesis for the cross sections. Several finite elements were assigned for each layer subjected to corrosion. At the same time the nodes of such finite elements were coincided. In this case, the initial modulus of elasticity and the characteristic strength of each of these elements were determined as $1/n_{fl}$, where n_{fl} is the number of finite elements simulating one layer.

After applying the load to the calculation models of the columns, a stepwise removal of finite elements simulated growth of the depth of concrete damaged with corrosion. This was the equivalent of an increase in the depth of corrosion damage.

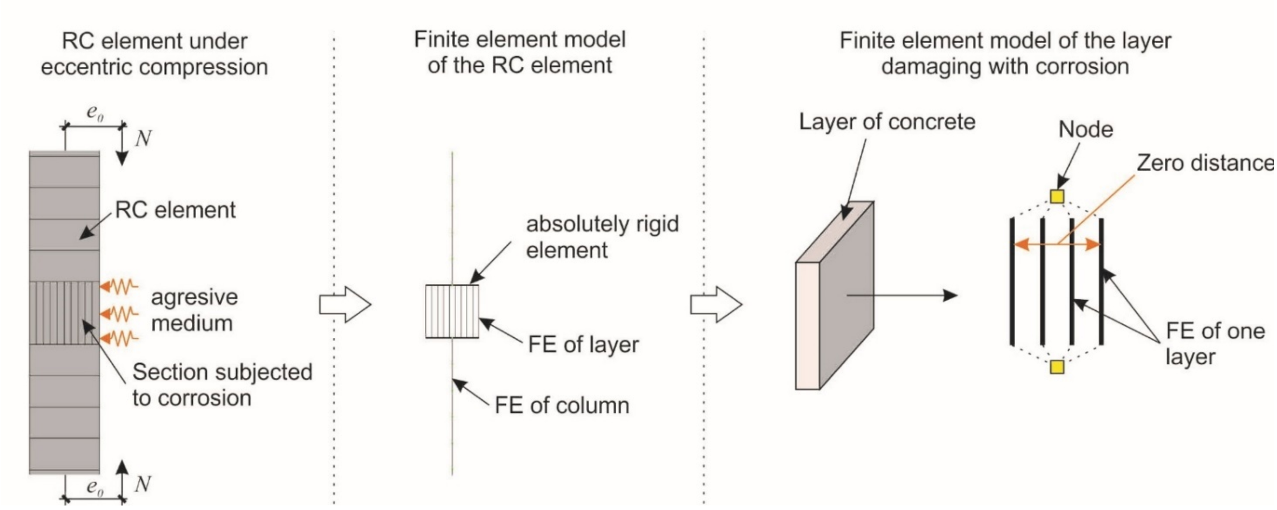
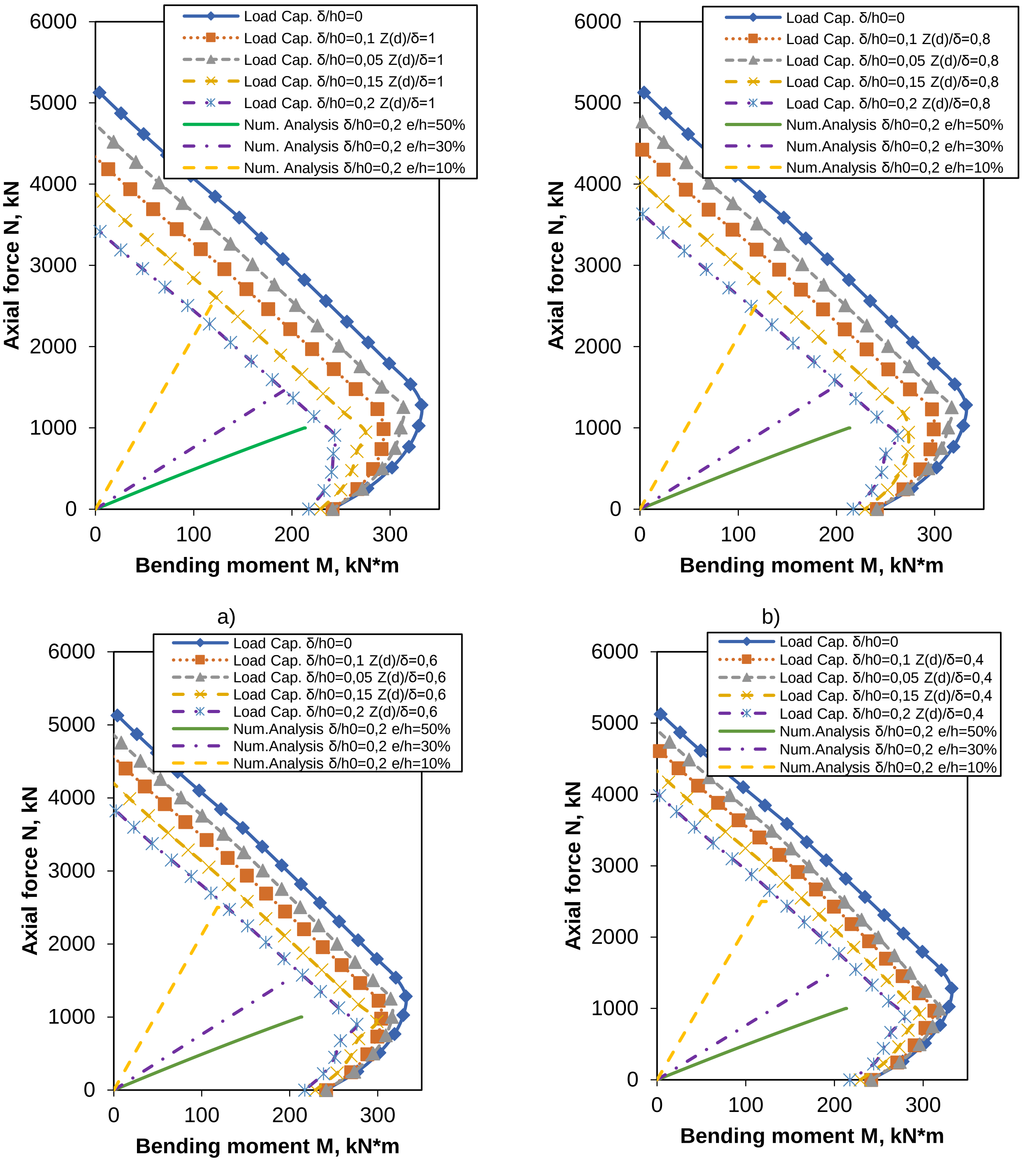


Fig. 2. Principle scheme for simulation of the deformation of a compressed reinforced concrete element damaging with corrosion

To evaluate the change in the load capacity of a reinforced concrete column damaging with corrosion, a cross section size of 400 x 400 mm was adopted. The column is a structural member of the facility moment resisting frame and exposed to aggressive medium action along all four faces. Adopted construction materials are as follows: concrete of class B30 (characteristic compressive strength of concrete cubes $f_{ck,cube}$ = 30 MPa, elasticity modulus E_c = 32500 MPa), longitudinal steel reinforcement is 4 bars of d = 32 mm A500 (f_{yd} = 500 MPa, E_s = 200000 MPa), a = a' = 50 mm. By varying the parameters of the corroded cross-sectional depth $\delta(t,t_0)$, the thickness of the conventionally destroyed depth z_d and slenderness ratio $\lambda_h = l_0/h$, we have constructed Axial Load vs. Moment interaction diagrams which are the boundaries of the areas of the bearing capacity of the column [20]. At the same time, we divide the right and left parts of Eqs. (3) and (4) by the moment magnification factor η to take into account the effect of slenderness of reinforced concrete corrosion-damaged column on its bearing capacity.

3 RESULTS AND DISCUSSION

Using above-mentioned models, this section provides the results of the assessment of the change in the load capacity of a reinforced concrete column. Fig. 3 and 4 present Axial Load vs. Moment interaction diagrams of the eccentrically compressed corrosion-damaged reinforced concrete column at varied values of above-mentioned parameters.



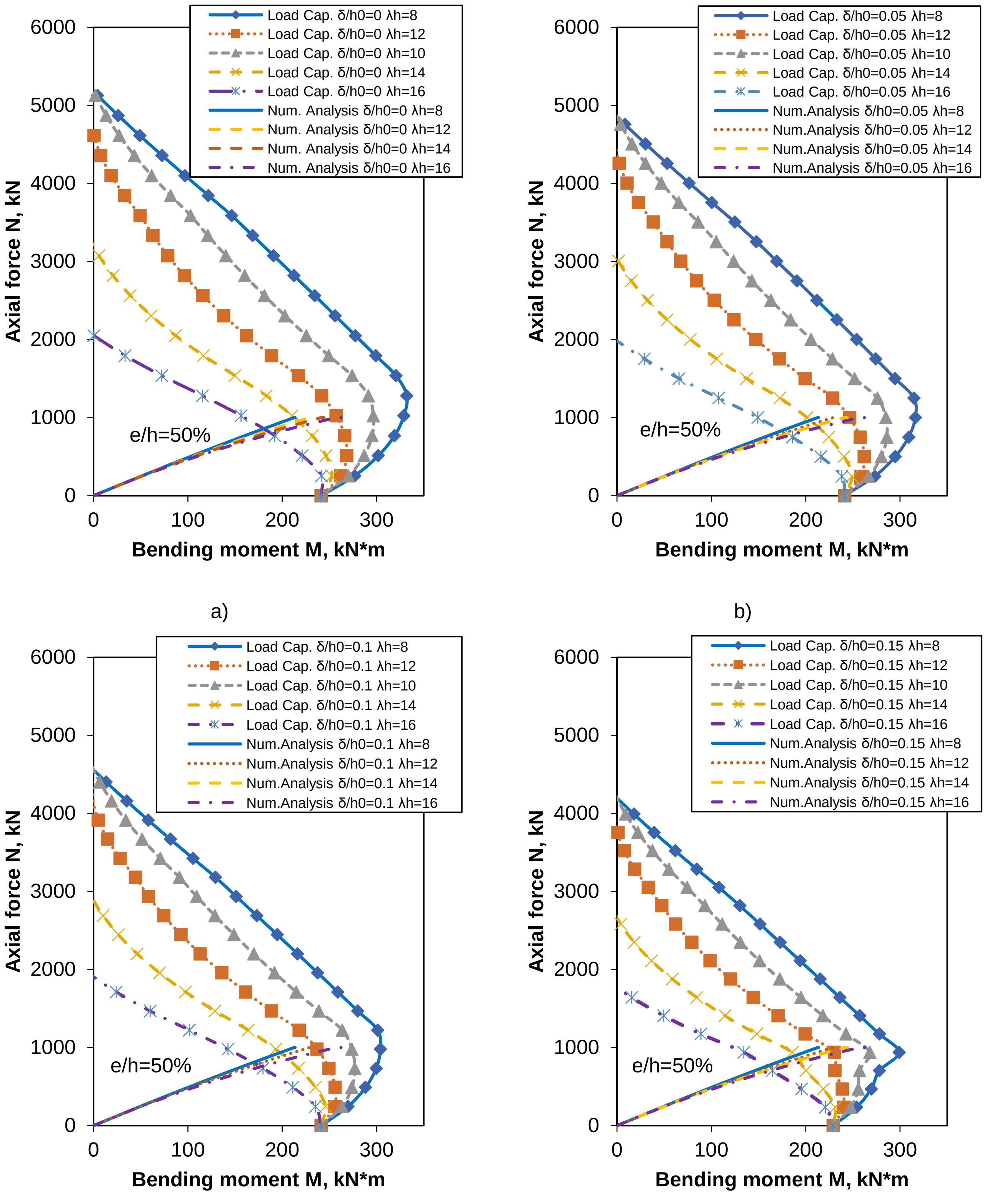
a)

b)

c)

d)

Fig. 3. Axial Load vs. Moment interaction diagrams for corroded eccentrically compressed reinforced concrete columns at slenderness ratio λ_h = 8 depending on the cross-sectional depth destroyed by corrosion: a) for z_d/δ = 1, b) for z_d/δ = 0.8, c) for z_d/δ = 0.6, d) for z_d/δ = 0.4



a) b) c) d)

Fig. 4. Axial Load vs. Moment interaction diagrams for corroded eccentrically compressed reinforced concrete columns at fixed destroyed to corroded depth ratio $z_d/\delta = 0.6$ depending on the slenderness ratio λ_h: a) $\delta/h_0 = 0$, b) $\delta/h_0 = 0.05$, c) $\delta/h_0 = 0.1$, d) $\delta/h_0 = 0.15$

An analysis of the graphs presented in Figures 3 and 4 shows that an increase in slenderness ratio from $\lambda_h = 8$ to $\lambda_h = 16$ leads to an increase in the 2nd order moment by 22%. At the same time, the bearing capacity of compressed elements decreased by 44% at relative eccentricity $e/h = 0.5$ and by 60% at $e/h = 0$ as slenderness ratio increased from $\lambda_h = 8$ to $\lambda_h = 16$. These ratios were retained for the elements with various corroded depth with an accuracy of 2%. At the same time fig. 3 indicates that with an increase in the depth of corrosion damage, a decrease in the bearing capacity occurs due to a decrease in the effective cross-sectional depth and increase the effective slenderness ratio. Thus, with slenderness ratio $\lambda_h = 8$ and fixed relative destroyed cross-sectional depth $z_d/\delta = 0.8$, the ultimate value of the axial force decreases up 11.4% for a relative depth of corrosion damage $\delta/h_0 = 0.2$. And the ultimate bending moment decreases up 21.0% compared to an undamaged column. In this case, the ultimate moment for flexure structural members ($N = 0$) decreases only when the longitudinal reinforcement bars are within the corrosion-damaged depth δ (see Fig. 3 at $\delta/h_0 = 0.15, 0.2$), since their effective cross-sectional area as well as bond strength decreases due to corrosion. It should be noted that a decrease in the relative destroyed depth introduced into the analysis leads to an increase in the ultimate value of the axial load for a fixed relative corroded depth δ/h_0. This can be explained by redistribution of stresses from damaged areas to undamaged ones for columns with small eccentricities of the axial load. At the same time, there is a downward shift of the ultimate moment point ($\frac{dM}{dN} = 0$) of the diagram. This occurs due to a decrease in the ultimate compressive strains $\varepsilon_{cu}^{cor}(t, z_d)$ for corroded cross-sectional depth. It is pertinent to note that the relative depth of the destroyed concrete z_d/δ, taken fixed when plotting the diagrams in Fig. 3, in fact, change during loading of a structural member. It realizes the mechanism of adaptation of the structure. Therefore, one should use the envelope of the *N*-*M* interaction diagram constructed at a fixed value of the relative depth of corrosion damage δ/h_0 and a variable value of the relative depth of the destroyed concrete z_d/δ to account the reserves of the bearing capacity.

Increase in the slenderness ratio λ_h over 12 (Fig. 4) leads to decrease in the value of the ultimate axial force ($M = 0$) perceived by eccentrically compressed columns with small eccentricity. At the slenderness ratio $\lambda_h = 16$, there is an almost twofold decrease in the ultimate axial load perceived by the column, and the ultimate moment corresponds to the case of transverse bending ($N = 0$). At the same time, an increase in the relative depth of corrosion damage enhances this effect due to an increase in the effective slenderness ratio of corrosion-damaged column compared to undamaged one.

Let us evaluate the robustness exposure of the column under continuous contact with a sulfate medium with pH = 3.5. To determine the parameters the kinetics of the corrosion damage process in the equation (2), the experimental data obtained by Zhou C. et al. [4] were accepted. Adopting $\delta(\infty, t_0) = 0.5h$ that corresponds to the corrosion of the entire section for medium action for 4 faces, the average value $\alpha = -0.00024$ was obtained. which practically does not change at varying the parameter *m*. The Figure 5 presents results for the time to reach the depth of corrosion damage δ_{cr} (t_{cr}, t_0) depending on the value of the parameter *m*.

For the considered reinforced concrete column, the time to reach the relative depth of corrosion damage $\delta/h_0 = 0.2$ with the avalanche damage trajectory ($m = -1$, $t = 1203$ days, Fig. 5) turned out to be almost 2 times less than the time to reach this depth with the descending damage kinetics ($m = 2.5$, $t = 2523$ days). With the trajectory of filtration damage, reaching the same depth of corrosion damage will take $t = 1488$ days.

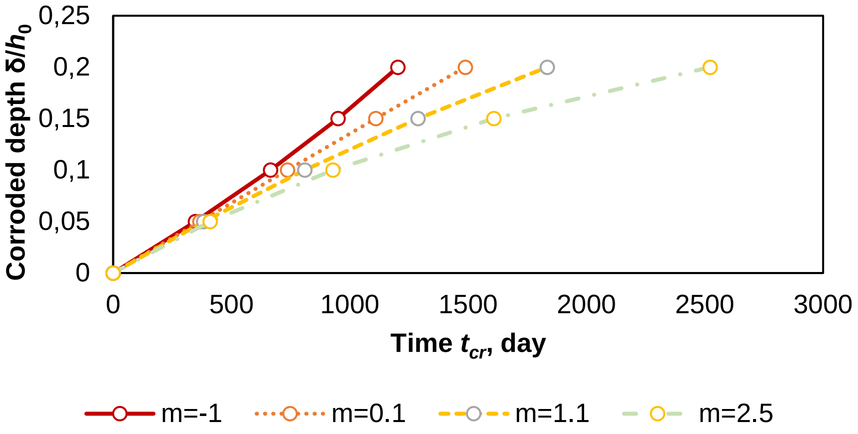


Fig. 5. Time t_{cr} to reach the critical value of a cross-section corroded depth $\delta_{cr}(t_{cr}, t_0)$ for adopted degradation function

4 CONCLUSION

The performed analysis of the influence of the depth of corrosion damage on the bearing capacity of eccentrically compressed reinforced concrete column of building frame, as well as the time of exhaustion of the bearing capacity, allows us to draw the following conclusions:

1. An increase in the depth of corrosion damage leads to a decrease in the bearing capacity occurs due to a decrease in the effective cross-sectional depth and increase the effective slenderness ratio. Thus, with slenderness ratio $\lambda_h = 8$ and fixed relative destroyed cross-sectional depth $z_d/\delta = 0.8$, the ultimate value of the axial force decreases up 11.4% for a relative depth of corrosion damage $\delta/h_0 = 0.2$. And the ultimate bending moment decreases up 21.0% compared to an undamaged column.
2. An increase in the slenderness ratio from $\lambda_h = 8$ to $\lambda_h = 16$ leads to an increase in the 2nd order moment by 22%. At the same time, the bearing capacity of compressed elements decreased by 44% at relative

eccentricity e/h = 0.5 and by 60% at e/h = 0 as slenderness ratio increased from $\lambda_h = 8$ to $\lambda_h = 16$. These ratios were retained for the elements with various corroded depth with an accuracy of 2%.

3. The time to reach the critical depth of corrosion damage depends significantly on the parameters of aggressive medium and the stress-strain state of the element under the action of dead and long-term live loads and may differ by several times when implementing trajectories of avalanche or descending kinetics of damage.

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