ISSN NO: 2770-4491
Date of Publication:06-11-2023

Choice of Design Model and Calculation Methods Optimization, Design Reliability Evaluation in Elastic and Elastic-Plastic Stages

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Abstract: The bearing capacity of the structure, determined by regulatory documents that limit the use of the plastic properties of the material, turns out to be underestimated. The current practice of optimal structural design (OPD) does not fully take into account the specific requirements (properties) for reinforced concrete structures. In this regard, research aimed at studying the assessment of the optimality and reliability of the structure both in the elastic and in the elastic-plastic stages of the material operation becomes relevant. Therefore, the authors attempt to assess the optimality and reliability of the design, taking into account a number of specific properties of reinforced concrete. In order to objectively assess the state of the structure in the elastic and elastic-plastic stages, a reliability assessment is carried out, which makes it possible to identify the possibilities of meeting the functional and operational requirements of the structure throughout the entire standard service life of the structure. As is customary in reliability theory, one of the main indicators for assessing reliability is the failure-free design, which takes into account the partial or complete loss of the functional properties of the system. The study proceeds from the fact that when solving optimization problems, a redistribution of efforts occurs due to a change (most often a decrease) in the parameters of the section of structural elements, which causes the elements to be predisposed to work in the elastic-plastic stage. The redistribution of forces leads to savings in materials, although inelastic deformations, the formation of cracks, and even partial decoupling of concrete with reinforcement, reduces the rigidity of structural elements. In order to study the design at the stages of both elastic and elastic-plastic, known methods and techniques are used.

Keywords:optimal design design,reliability, failure-free design, deformation, stress- strain state , structural system, reinforced concrete, elastic and elastic-plastic properties of the material, super element.

Introduction

Modern practice of computational methods for optimal design of a structure shows that in order to achieve success in solving problems of the defense industry, it is necessary to take into account all the specific properties of the structure, especially the elastic and elastoplastic properties of the material. The bearing capacity of the structure, determined according to regulatory documents that limit the use of the plastic properties of the material, turns out to be underestimated. The existing practice of the defense industry does not fully take into account the specific requirements (properties) for reinforced concrete structures. In this regard, research aimed at studying the assessment of the optimality and reliability of the structure both in the elastic and in the elastic-plastic stages of the material operation becomes relevant. Therefore, we are making an attempt to assess the optimality and reliability of the structure, taking into account a number of specific properties of reinforced concrete.

As shown by the results of studies conducted by the authors in [1,2,3], the designed structural system in the elastic stage has reserves due to the elastic-plastic properties of reinforced concrete. Optimization within certain limits in the elastic-plastic stage leads to additional savings in materials, labor costs, etc.

In order to objectively assess the state of the structure in the elastic and elastic-plastic stages, a reliability assessment is carried out, which makes it possible to identify the possibilities of meeting the functional and operational requirements of the structure throughout the entire standard service life of the structure.

As is customary in reliability theory, one of the main indicators for assessing reliability is the failure-free design, which takes into account the partial or complete loss of the functional properties of the system. In the

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work on assessing the reliability of systems, well-known methods are used, as well as the ideas proposed in [4,5].

In the study of the design, taking into account the elastic-plastic properties. We proceed from the fact that when solving optimization problems, a redistribution of efforts occurs due to a change (most often a decrease) in the parameters of the section of structural elements, which causes the elements to be predisposed to work in the elastic-plastic stage. The redistribution of forces leads to savings in materials, although inelastic deformations, the formation of cracks, and even partial decoupling of concrete with reinforcement, reduces the rigidity of structural elements. In order to study the design at the stages of both elastic and elastic-plastic, known methods and techniques are used.

Purpose of the study.

The aim of the study is to:

- to determine the optimal area of the bearing capacity of the system in the elastic stage with the transition to the elastic-plastic one;
- determine the optimal area with an assessment of the reliability of the system in the elastic and elastic-plastic stages.

Methods of calculation.

To solve this goal, we use a technique that combines several procedures for calculating, designing, optimizing and evaluating reliability: for static calculation - the finite element method - (FEM), the method of successive loadings (approximations), optimization methods: coordinate-wise descent and random search; reliability assessment method, IBM personal computer.

The technique aims to simulate the stress-strain state (SSS) of the structure and determine the optimal parameters of the system under static loading , taking into account the transition of some elements from the elastic to the elastic-plastic state, the loading of the structure continues until one of the elements of the system fails.

The calculation is based on the FEM and is reduced to the matrix equation

$$Kz + P = 0 \quad (1)$$

where, $K = P' R P$ - frame stiffness matrix,

z \u003d $-K^{-1} P$ \u003d $-(P'R P) P$ generalized displacements. (2)

Moreover, the stress matrix can be defined

$$S = Qz = -Q(P'R P)P \quad (3)$$

The elastic and elastic-plastic stages of work are taken into account in the design procedure.

O optimization of the design parameters is carried out using the developed optimization method [4,5], and the reliability assessment is based on the requirement $P(M_{np} > M_p)$ - the probability of the system fail-safe.

To obtain answers to the questions posed, a machine experiment is involved, which does not require significant material costs. Let us formulate the main goals (tasks) of the machine experiment:

- to investigate the change in the optimality criterion during the transition of structural elements from the elastic to the elastic-plastic stage (due to a change in the cross-sectional area) under static loading of the frame;
- to determine the optimal parameters of the frame $\xi_{opt} = E I_{cm} / EI_p$, where ξ - (the ratio of the bending stiffness of the post to the bending stiffness of the crossbar) for various types of loads with different geometry of the frame axes of the considered superelement (SEL) - in the elastic and elastic-plastic stages of work structures (under static loading of the system);
- evaluate the reliability of the optimal system in the elastic and elastic-plastic stages of work;
- to determine the design parameters corresponding to the required level of regulatory reliability of the system, as the boundary of the transition to the state of system failure.

As revealed in [4, 2], any system, including a frame system, consists of a number of typical SELs, the total indicators of which are equivalent to the nature of the system indicator. In particular, when calculating flat frames, a portal frame (Fig. 1 a) and a closed loop are taken as SEL(Fig.1 b), which may have different modifications (Fig.1 c, d , e.e)

ISSN NO: 2770-4491
Date of Publication:06-11-2023

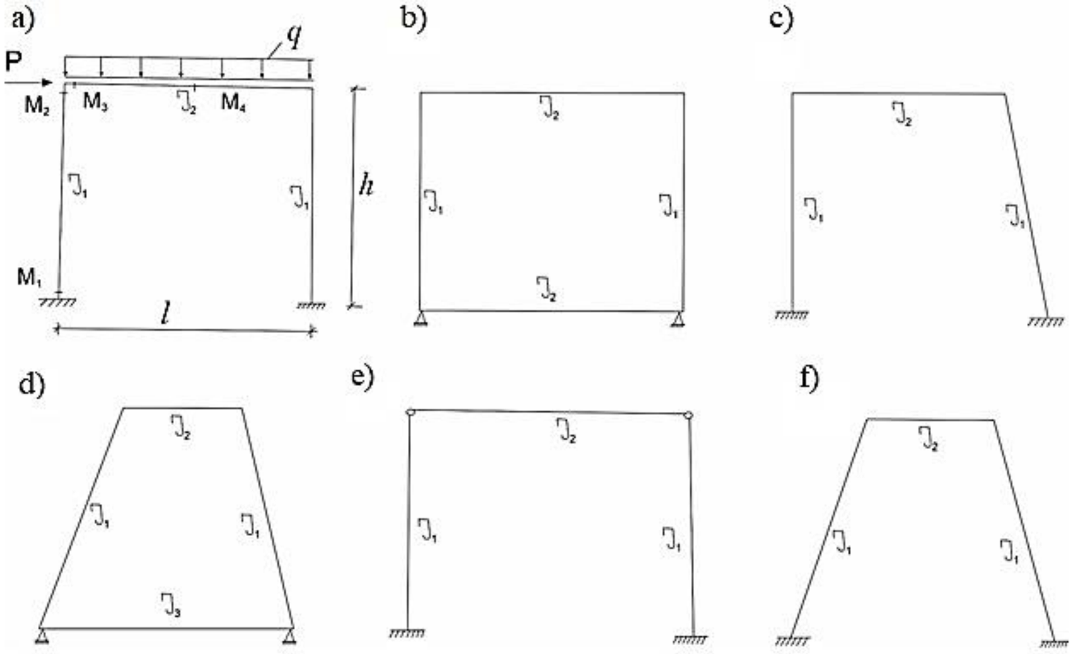

Fig. 1. Calculation scheme of the studied SEL (a) and their modifications (b, c, d, e, f).

The calculation of complex systems, such as multi-story, multi-span frame systems, is laborious even with the use of a computer. The calculation of such systems in the elastoplastic stage requires additional costs. Therefore, at this stage, simple SEL subsystems are considered, and the conclusions drawn from them will be generalized for complex systems.

Taking into account the redistribution of forces, in the process of optimization, in the elements of the frame can be done in different ways. The limit equilibrium method considers the structure at the moment of exhaustion of its bearing capacity.

The method for calculating reinforced concrete structures according to the limit state for the entire structure, which involves taking into account the elastic-plastic properties of the material, is based on fundamental research by such scientists as: A.A. Gvozdev, V.G. Nazarenko , N.N. Skladnev, S.M. Krylov .

Consider the application of the limit equilibrium method to calculate *n* - times statically indeterminate frames. In this case, we will adhere to the following accepted properties of the structure:

-sections in elements where the bending moment is less than M_{crc} work elastically; where M_{crk} is the cracking moment;

-sections in elements where the bending moment is equal to or greater than M_{crc} will pass to a plastic hinge;

- the mutual rotation of the sections during the transition to the plastic state will increase without much increase in the bending moment in the section;
- in the stage of elastic-plastic work, the structure exists until the appearance of no more than *n* - the number of hinges.
- longitudinal forces in bending elements do not play a significant role.

As is known, the transition to the elastic-plastic stage will begin with the formation of cracks and, subsequently, plastic hinges. The critical state of the system is the formation of *n* - the number of hinges, because the occurrence of *n* + 1 hinges leads to unsuitability for operation due to the exhaustion of the bearing capacity of the structure or its part (the structure can achieve such a state under certain deformations). Immediately before the exhaustion of the carrying capacity, the maximum possible case of equilibrium occurs, i.e. when, with increasing load, it is necessary to maintain a balance between internal and external forces.

Since the number of critical-characteristic sections C_k always exceeds the degree of indeterminacy *n* , the process of formation of parameters can easily cross the critical boundary and reach the level $C_k > n$. Therefore, the calculation does not allow bringing the formation of hinges in all *n* - sections.

For clarity, consider a test example by which you can determine the bearing capacity of the structure. Determination of the parameters of the cross-section of elements with EL in the elastic-plastic stage of work.

As is known, [6] a reinforced concrete beam, in our case, a finite element, when bent in the elastic stage, has a curvature

$$\chi_{yn} = \frac{1}{r} = \frac{M}{B_y} \qquad (4)$$

Beyond the elastic limit ($M_r > M_{crc}$), the curvature increases mainly due to a decrease in stiffness, and the linear dependence ψ_i on bending moments is violated.

To take into account the work of structural elements in the elastic-plastic stage, it is necessary to determine the value of χ or B for each characteristic section.

The transition to the elastic-plastic stage is accompanied by the appearance of cracks, which exclude the operation of the stretched concrete zone. The deformations of compressed concrete ε_b and tension reinforcement ε_a will not be the same in length, their average value is recorded

$$\varepsilon_{b\text{cp}} = \psi_b \varepsilon_b \qquad \varepsilon_{a\text{cp}} = \psi_a \varepsilon_b \qquad (5)$$

where, ψ_a is the coefficient of proportionality, in a simplified form having the dependence

$$\psi_a = 0.5 + \varphi_b \frac{M_{b\text{T}}}{M} \qquad (6)$$

at the same time φ_b- takes into account the type of reinforcement (if smooth φ_b= 0.7, periodic profile φ_b= 0.6).

M_{bt}- Bending moment perceived by concrete before cracking, M - acting moment.

In the section, by applying a longitudinal force to the center of gravity of the tensile reinforcement, two stresses can be obtained

$$\sigma_s = \frac{M_1}{ZA_s} + \frac{N}{A_s}\ ; \qquad \sigma_b = \frac{M_1}{ZA_n} \qquad (7)$$

where, z is the arm of the internal pair of forces,

$$A_n = A_b + \frac{E_s}{vE_b} A_s (8)$$

- reduced area of the compressed zone of the section,

E_b is the modulus of elasticity of concrete,

v- coefficient taking into account the shape of the section.

Knowing that there is a dependence and substituting the expressions for σ_s and σ_b we get

$$\varepsilon_s = \frac{\varphi_s}{E_s A_s}\left(\frac{M_1}{z} + N\right); \qquad \varepsilon_b = \frac{\varphi_b}{vE_b A_n}\frac{M_1}{z} \qquad (9)$$

and their average values

$$\varepsilon_{s\ \text{cp}} = \frac{1}{E_s A_s}\left(\frac{M_1}{z} + N\right); \qquad \varepsilon_b = \frac{1}{vE_b A_n}\frac{M_1}{z} \qquad (10)$$

The curvature of the bending line, as is known, can be expressed in terms of average relative strains

$$\chi = \frac{\varepsilon_{s\ \text{cp}} - \varepsilon_{b\ \text{cp}}}{h_0} \qquad (11)$$

If we substitute the expression for $\varepsilon_{s\ \text{cp}}$ and $\varepsilon_{b\ \text{cp}}$ then we get

$$\chi = \frac{M_1}{h_0 z}\left(\frac{\psi_s}{E_s A_s} + \frac{\psi_b}{vE_b A_n}\right) + \frac{N}{h_0}\frac{\psi_s}{E_s A_s} \qquad (12)$$

Whence the rigidity during the formation of cracks of a bent element (at N = 0) is equal to

$$B = \frac{h_0 z}{\frac{\psi_s}{E_s A_s} + \frac{\psi_b}{vE_b A_n}} \qquad (13)$$

Starting position:

-construction elements of PEL without prestressing with a rectilinear section are considered.

The following steps are introduced into the basis of the SEL calculation algorithm:

- calculation of the structure in the elastic stage is given according to the FEM,

$$S = Q(\Pi' R \Pi)^{-1} R_p \qquad (14)$$

where, Qis the shear force matrix, R (g) is the stiffness matrix of the finite element, P is the coordinate transformation matrix,

Π'-transposed matrix, R_p –a matrix of static loads based on control parameters, having the form:

$$q = \left\{ \frac{EJ_{cm}}{EJ_P}; \frac{EA_{cm}}{EA_P}; \dots; \mu \right\} \quad (15)$$

- selection and verification of reinforcement sections is carried out according [7]to the strength condition $M \leq R_b S_b + R_s S_s$ (16)

- the transition from the elastic to the elastic-plastic stage is determined from the condition $M_r < M_{crc}$;

- cracks or a plastic hinge appear in the most loaded section, which can be detected by calculation;

- the rigidity of the elements, taking into account the formation of cracks and plastic deformations of concrete;

- reinforced posts are considered normal, corresponding to the case $\xi \leq \xi_k$, symmetrical, and in both posts the cross-sectional area of \u200b\u200bthe reinforcement is the same;

- the optimization process in both the elastic and elastoplastic stages is carried out according to the accepted goal function, which acts as the cost of construction materials "in action" for the SEL:

$$C_o = L_{cm}(2A_b^{cm}C_b + 2(A_s + A_s')^{cm}C_s) + \left(A_b^p C_b + (A_s + A_s')^p C_s\right)L_p \quad (17)$$

where A_b^{cm}, $A_b^p$is the cross-sectional area of the post and crossbar,

C_s- cost of 1 m ^{3} of reinforcement, C_b- cost of 1 m ^{3} of concrete, A_s- respectively, the area of stretched and compressed reinforcement.

Conclusion

The research is aimed at evaluating the optimality and reliability of the structure, studied using computational methods, both in the elastic and in the elastoplastic stages of the work of the material. For this purpose, a calculation model and calculation methods were chosen, which makes it possible to identify the possibilities of meeting the functional and operational requirements of the structure throughout the entire standard service life of the building and structure.

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