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Studies On The Resistance And Fire Resistance Of Reinforced Concrete

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ABSTRACT

This research paper deals with the study of the resistance and fire resistance of concrete structures by studying the theories of Galileo Galilei, I. Coulibin, Louis Navier, Arthur Loleit, J. Bernoulli, R. Guk, J.M. Tuglie, V.A. Baldina, A.A. Gvozdev, I.I. Goldenblat, Yu.M. Ivanova, V.M. Keldysh, V.M. Kochenova, L.I. Onishchik, N.S. Streletsky, K.E. Tal, A.V. Zhitkevich, V.M. Moskvin, V.V. Kuraev, P.P. Gedeonov and draws attention to the special properties of vermiculite as a heat-insulating material, taking into account the experience of its use both in Russia and in the United States of America.

KEYWORDS

Reinforced concrete resistance, refractory concrete, classification of refractory material, Portland cement, slag Portland cement, liquid glass, alumina cement.

INTRODUCTION

Issues related to the study of the resistance and fire resistance of concrete structures have always been the focus of attention of researchers striving for maximum safety, including fire safety in the construction of both industrial facilities and housing. Experimental studies to study the joint work of two materials with different physical and mechanical properties - concrete and steel reinforcement -

were carried out from the very beginning of the appearance of reinforced concrete.

Experiments have shown that nonlinear deformations of concrete and cracks in stretched zones have a significant effect on the stress-strain state of reinforced concrete elements. The assumptions of a linear relationship between stresses and deformations, and the formulas for the resistance of elastic materials for reinforced concrete based on these assumptions, often turned out to be unacceptable. The theory of reinforced concrete resistance is based on experimental data and the laws of mechanics, and proceeds from the actual stress-strain state (SSS) of elements at different stages of loading by an external load. With the accumulation of experimental data, methods for calculating reinforced concrete structures have been improved. In the meantime, all calculation formulas are empirical due to the complexity of the concrete structure (anisotropic material). In the development of the theory of reinforced concrete resistance, three periods can be distinguished. The foundations of this science were laid by the works of Galileo Galilei (1564-1642).

Studying in 1638 the bending and axial tension of the beams, he accepted the value of the breaking load as a criterion for load strength. The beginning of the third period was laid in 1905 by the work of Arthur Loleith "On the question of the rules for the acceptance of reinforced concrete structures." He proposed to consider in calculations the instantaneous equilibrium preceding the moment of destruction of the structure.

METHODS OF RESEARCH

Since concrete does not take part in the tensile resistance, the factor that led to the uncertainty of the solution to the problem was excluded from the calculation: the neutral axis occupied a certain position. Navier's theory, which was later called classical, was based on the following assumptions: the stage of operation and the stage of destruction are similar - the ratios of efforts, stresses and deformations for both stages are the same; sections that are flat before deformation remain the same after it (the hypothesis of flat sections by J. Bernoulli); stresses are proportional to relative elongations (R. Hooke's law). From these assumptions new ones followed: stresses in the fibers of a bent element increase in proportion to their distance from the neutral axis (L. Navier's law); the modulus of elasticity of a given material is a constant value. The foundations of the classical theory of reinforced concrete were created in 1876-1890. These were the years of successful development of steel structures, so the new, then little studied material "reinforced concrete" was squeezed into the framework of the classical provisions of the resistance of an elastic and homogeneous (isotropic) material, which can be considered steel, but not reinforced concrete. Therefore, none of the hypotheses mentioned above, which form the basis of the classical theory of reinforced concrete, is, strictly speaking, not valid. Due to the difference in the properties of concrete and steel, the picture of the stressed and deformed state of a bent reinforced concrete element continuously changes as the load on it increases. In 1880, professor of the Lviv Polytechnic Institute Zh.M. Toulier recorded two stages of the stress state, the number of which was later increased to three. These stages of the stress-strain state were used as the basis for modern calculations of the cross-section of reinforced concrete structures, and a method for calculating the allowable stresses was proposed. Historically, the method for calculating the strength of sections of bending elements based on permissible stresses was formed first. At the beginning until the XX century. in it, stage II of the stress-strain state was taken as a basis and the following assumptions were made: the concrete in the tensile zone does not work, tensile stress is absorbed by the reinforcement; the concrete of the compressed zone works elastically, and the relationship between stresses and deformations is linear according to Hooke's law; sections normal to the longitudinal axis, flat before bending, remain flat after bending, and the hypothesis of flat sections is applied; the reduced concrete section is used, in which the reinforcement is replaced by an equivalent section for the strength of concrete; allowable stress:

$$\sigma_{adm} = P / K, \quad (1)$$

where K – generalized safety factor; P – operating load.

As a consequence of these assumptions, a triangular stress diagram and a constant ratio of the elastic moduli of materials are taken in concrete in the compressed zone:
$a = E_s / E_b$ (fig 1).

Consider the reduced homogeneous section in which the sectional area of the tensile reinforcement A_s is replaced by a concrete sectional area equal to aA_s, and the sectional area of the compressed reinforcement A'_s – sectional area of concrete aA'_s based on the equality of deformations of concrete and reinforcement:

$$\varepsilon_s = \sigma_s / E_s = \varepsilon_b = \sigma_b / E_b. \quad (1.1)$$

Thus, using relation (1.1), it is possible to establish the relationship between stresses in reinforcement and concrete:

$$\sigma_s = a\sigma b, \quad (1.2)$$

$\alpha = \frac{E_s}{E_b}$ where is the ratio of the modulus of elasticity of reinforcement and concrete.

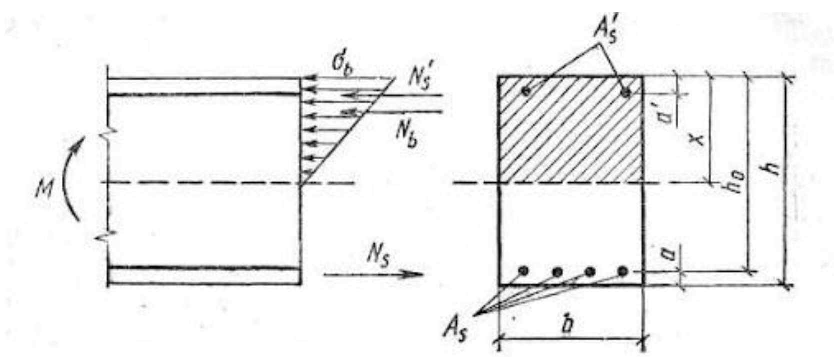

Figure 1. Calculation of a rectangular beam for permissible stresses

The edge stress in concrete is determined as for the reduced homogeneous section:

$$\sigma_b = Mx / I_{red} \quad (1.3)$$

where x – compression zone height; σ_s and σ'_s – stress in tensile and compressed reinforcement; I_{red} – moment of inertia of reduced section; M – external force factor.

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$$\sigma_s = \alpha \frac{M(h_0 - x)}{I_{red}},$$

$$\sigma_s' = \alpha \frac{M(x - a')}{I_{red}}, \quad (1.4)$$

where h_0 – working (useful) section height; ***h*** – total section height; ***a*** – distance from the axis normal to the plane of bending and passing through the center of gravity of the section of tensile reinforcement to the outer edge of the section; ***a'*** – distance from the axis normal to the plane of bending and passing through the center of gravity of the sections of the compressed reinforcement to the outer compressed edge of the section. The height of the compressed zone of the section χ are found from the condition that the static moment of the reduced section relative to the neutral axis is zero:

$$S_{red} = \frac{bx^2}{2} + \alpha A_s'(x - a') - \alpha A_s(h_0 - x) = 0.$$

The moment of inertia of the reduced section will be:

$$I_{red} = bx^3/3 + \alpha A_s(h_0 - x)^2 + \alpha A_s'(x - a').$$

Stresses in concrete and reinforcement are limited by permissible stresses, which are set as some fractions of the ultimate strength of concrete to compression $\sigma_b = 0{,}45R$ (where, ***R*** – concrete grade, taken equal to the cube strength of concrete) and the yield strength of the reinforcement $\sigma_s = 0{,}5\sigma_y$.

The main disadvantage of the method for calculating sections by permissible stresses is that concrete is considered as an elastic material. The actual distribution of stresses in concrete over the section in stage II does not correspond to a triangular stress diagram, ***a*** – the distance is not constant, depending on the value of the stress in the concrete, the duration of its action and other factors. Establishing different values of the number α depending on the class of concrete does not help either. It was found that the actual stresses in the reinforcement are less than the calculated ones. This calculation method not only makes it impossible to design a structure with a predetermined safety factor, but also does not allow determining the true stresses in materials. In some cases, this leads to excessive consumption of materials, requires the installation of reinforcement in the concrete of the compressed zone, etc. The disadvantages of the calculation method for permissible stresses were especially pronounced when new types of concrete were introduced into practice (heavy concrete of high classes, lightweight concrete based on porous aggregates) and high strength reinforcing steels. This prompted Soviet scientists to carry out special studies and develop a calculation method that would better meet the elastoplastic properties of reinforced concrete and would make it possible to abandon the calculation method for permissible stresses. This method was the method of calculation for destructive forces, introduced into the Norms in 1938. The method for calculating sections by breaking forces is based on stage III of the stress-strain state during bending. The work of the concrete in the tension zone is not considered. In the calculation formulas, instead of the permissible stresses, the compressive strength of concrete and the yield strength of the reinforcement are introduced. This eliminates the need to use the number a. The diagram of stresses in concrete in the compressed zone was initially assumed to be curved and then rectangular. The force allowed during operation of the structure is determined by dividing the destructive force by the overall safety factor ***k***. So, for bending elements:

$$M = M_p / k, \quad (1.5)$$

and for compressed elements:

$$N = N_p / k. \quad (1.6)$$

When determining the destructive forces of elements operating in case 1 (1.5), the destruction of which begins also in the stretched zone, instead of the hypothesis of flat sections, the principle of plastic destruction is used, first substantiated by the Soviet scientist A.F. Loleith.

On the basis of this principle, according to which the stresses in reinforcement and concrete reach their limiting values simultaneously, the design formulas for the destructive forces of bending and centrally loaded elements were obtained. For a bending element with any symmetrical cross-section (Figure 2), the height of the compressed zone is determined from the equation of equilibrium of internal forces in the fracture stage:

$$R_u A_b + R_s A'_s = R_s A_s, \quad (1.7)$$

where R_u – the ultimate resistance of concrete to compression in bending, which is assumed to be 1,25 R_b; R_s – reinforcement yield strength; A_b – sectional area of the compressed concrete zone. The breaking moment is defined as the moment of internal forces relative to the axis passing through the center of gravity of the stretched reinforcement:

$$M_p = R_u S_b + R_s A'_s \left(h - a' \right), \quad (1.8)$$

where $S_b = A_b z_b$ – static moment of the sectional area of the compressed zone of concrete relative to the axis passing through the center of gravity of the section of the tensioned reinforcement; z_b – the distance from the center of gravity of the section of the tensioned reinforcement to the center of gravity of the sectional area of the compressed zone of concrete. The boundary between case 1 (1.7) and case 2 (1.8) is established on the basis of experimental data. At $S_b / S_0 \le 0{,}8$ there is a case 1 (S_0 – the static moment of the entire working area of the concrete section relative to the axis passing through the center of gravity of the section of the tensioned reinforcement). For rectangular and T-sections with a flange in the compressed zone, the boundary value of the height of the compressed zone $x = 0{,}55h_0$.

Thus, when calculating by this method, the formulas take into account the safety factor - the same for the element as a whole. The safety factor k was established by the norms depending on the cause of the destruction of the structure, the combination of force effects and the ratio of forces T_v from temporary loads to efforts T_g from constant loads. In the case of a predominance of live load, overloading of the structure is more likely, and the safety factor should be higher. So, for slabs and beams k = 1,8 with the main combination of loads and ratio $T_v / T_e \le 2$, k = 2 at $T_0 / T_g > 2$ etc. For prefabricated prefabricated structures with basic and additional combinations of loads, the safety factor decreased by 0,2.

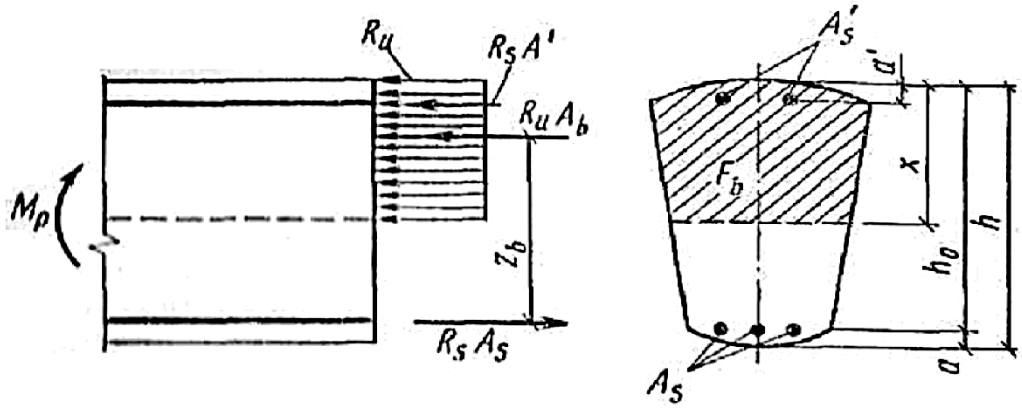

Figure 2. Calculation of a beam of any symmetrical section for breaking forces

In the calculations of sections for breaking forces, the internal forces M, Q, N from the load are also determined at the stage of destruction of the structure, i.e., taking into account the formation of plastic hinges. For many types of structures - slabs, continuous beams, frames - such calculations give a significant economic effect. The method of calculation for destructive forces, taking into account the elastic-plastic properties of reinforced concrete, more accurately reflects the actual work of the structural sections under load and is a serious development of the provisions of the theory of reinforced concrete resistance. The big advantage of this method in comparison with the calculation method for permissible stresses is the ability to determine a general safety factor that is close to reality. When calculating by breaking forces, in some cases, a lower consumption of reinforcing steel is obtained in comparison with the consumption of steel by the method of permissible stresses (for example, in bending elements, compressed reinforcement is usually not required by calculation by this method). The disadvantage of the method for calculating sections by destructive forces is that possible deviations of actual loads and strength characteristics of materials from their calculated values cannot be explicitly taken into account with one general synthesizing safety factor. Therefore, a more progressive method for calculating the limit states was proposed. In the calculations of cross-sections for limiting states, they use the prerequisites underlying building codes and regulations: internal forces in the design section of the element are determined for the stage (instant) of its destruction; with the help of a system of coefficients introduced to the strength characteristics of materials, their operating conditions and loads, the forces at the stage of destruction lead to efforts at the stage of operation; considering the cross-section passing along the crack in tensile concrete, the tensile strength of concrete is taken to be zero;

The compressive strength of concrete is represented by stresses equal to R_{np}, and the stress diagram is taken rectangular;

Tensile stresses in the reinforcement take no more than the design resistance R_a, compressive (if there is a design reinforcement in the compression zone) - no more than the design resistance R_{ac}.

Later, by the work of the Soviet school of iron concrete workers, the calculation by the stage of destruction was extended to eccentrically compressed elements, elements with rigid reinforcement, to the calculation of the strength of inclined sections, annular and circular sections, etc. The current standards establish two groups of limit states: by bearing capacity; for suitability for normal use. The limiting state of the structure is called, upon reaching which it loses its ability to resist the effects of loads (forces) or receives excessive deformations or local damage. The method for calculating structures by limiting states is a further development of the method for calculating destructive forces. When calculating using this method, the limiting states of structures are clearly established and a system of design coefficients is used, the introduction of which guarantees that such a state will not occur under the most unfavorable combinations of loads and with the lowest values of the strength characteristics of materials. The strength of the sections is determined by the stage of destruction, but the safety of the structure under load is assessed not by one synthesizing safety factor, but by the specified system of design factors. Structures designed and calculated using the limit state method are somewhat more economical.

As a progressive, ahead of its time, this method was first introduced into the new standards for the design of building structures in 1955.Since then and up to the present, the calculation of reinforced concrete structures has been performed using the limit state method. By "limiting" is meant such a state of the structure, after reaching which, further operation becomes impossible due to the loss of the ability to resist external loads or receive unacceptable displacements or local damage. In accordance with this, two groups of limiting states have been established:
Calculations for the limiting states of the first group should provide an element (structure) from brittle, ductile, fatigue failure, loss of stability or position, failure from the combined effect of force factors and the external environment. Calculations for the limiting states of the second group should ensure the protection of the structure from the formation of cracks, excessive or prolonged opening, displacements (deflections, angles of rotation and skew, vibrations) exceeding the permissible ones. Calculation according to the first group of limiting states is performed in order to prevent structural failure (strength analysis), loss of stability of the structure shape (buckling calculation) or its position (overturning or sliding calculation), fatigue failure (fatigue analysis). The calculation for the second group of limiting states is aimed at preventing the development of excessive deformations (deflections), excluding the possibility of cracking in concrete or limiting the width of their opening, as well as to ensure, if necessary, the closure of cracks after removing part of the load. The calculation for the first group of limiting states is the main one and is used in the selection of sections. The calculation for the second group is performed for those structures that, being strong, lose their performance due to excessive deflections (beams of large spans with a relatively low load), cracking (tanks, pressure pipelines) or excessive crack opening, leading to premature corrosion of reinforcement. Reinforced concrete structures must meet the design requirements for two groups of limiting states, which were indicated above, namely: by bearing capacity (first group); by suitability for normal use (second group). The calculation of the limiting states of the first group is performed to prevent the following phenomena: fragile, ductile or other nature of destruction (strength calculation, taking into account, if necessary, the deflection of the structure before destruction); loss of stability of the shape of the structure (calculation for the stability of thin-walled structures, etc.) or its position (calculation for overturning and sliding of retaining walls, eccentrically loaded high foundations); calculation for the

emergence of buried or underground reservoirs, etc .; fatigue failure (calculation of the endurance of structures under the influence of a repetitive moving or pulsating load: crane beams, sleepers, frame foundations and floors for unbalanced machines, etc.); destruction from the combined effect of force factors and unfavorable influences of the external environment (aggressiveness of the environment, alternating freezing and thawing, etc.). The calculation of the longitudinal states of the second group is performed to prevent the following phenomena: formation of excessive and prolonged opening of cracks (if they are permissible under operating conditions); excessive movement (deflections, angles of rotation, angles of misalignment and amplitude of vibration).

CONCLUSION

Consequently, calculations of the limiting states of the structure as a whole, as well as of its individual elements or parts, are performed for all stages - manufacturing, transportation, installation and operation. In this case, the design schemes must comply with the adopted design solutions and each of the listed stages.

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