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CALCULATION OF REINFORCED CONCRETE STRUCTURES TAKING INTO ACCOUNT INELASTIC PROPERTIES OF MATERIALS

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Abstract
The article provides a general description of methods for calculating statically indeterminate reinforced concrete structures and the influence of complex structural solutions, especially of monolithic reinforced concrete, which are widely used in modern construction. The conditions for the use of limit equilibrium methods for calculating the load-bearing capacity of structures, taking into account the increase in plastic deformations, are analyzed, and the rules that must be observed when designing reinforced concrete structures by the limit equilibrium method are proposed.

Keywords: statically indeterminate construction, inelastic properties, inelastic deformations, ultimate equilibrium, redistribution of forces.

Introduction

Statically indeterminate reinforced concrete structures and complex structural solutions, especially of monolithic reinforced concrete, are widely used in modern construction. Among such design solutions are spatial multi–span frames of buildings with regular and irregular grid of columns and walls, monolithically connected with floor slabs, transition slabs and structurally heterogeneous foundation slabs, frames of high-rise buildings with heavily loaded massive columns, walls and cores of rigidity, etc. However, the methods of calculation and design of such structures are practically not reflected in CMC 2.03. 01-96 "Concrete and reinforced concrete structures. Basic provisions" [1-12], which mainly provides instructions for the calculation of the simplest reinforced concrete structures (planar structures such as beams, walls, floor slabs), taking into account the inelastic properties of concrete and reinforcement.

In the practice of design, as is known, the construction mechanics of elastic systems is used to calculate statically indeterminate structures. However, in order to correctly assess the load-bearing capacity, it is necessary to take into account the inelastic properties of materials.

Calculation of structures by the method of marginal equilibrium.

One of the methods of accounting for inelastic properties of materials is the limit equilibrium method (MPR).

The application of the limit equilibrium method provides for compliance with the following prerequisites:
deformations of the structure until its load-bearing capacity is exhausted must be small so that changes in geometric quantities included in the equilibrium conditions can be neglected;
the forces in the structural elements, especially determining its actual bearing capacity, should be limited by the limiting conditions under which the deformations of these elements can increase indefinitely.
It is possible to check by two methods of MPR: static and kinematic.
In the static MPR method, when both prerequisites are fulfilled, the load corresponding to the limit of the bearing capacity of structures will be the greatest, at which it is still possible to simultaneously observe both the equilibrium conditions and the limiting conditions for all elements of the system. In the kinematic method of MPR, the load value is equal to the smallest of the values determined by the equality of the work of external forces and the maximum internal forces on any possible movements. The possible displacement resulting in this lowest value determines the fracture pattern of the structure when the load-bearing capacity is exhausted.
Depending on the type of construction, both static and kinematic methods can be applied. If the latter, with known fracture schemes, gives simpler expressions of the bearing capacity, then the static method does not require knowledge of fracture schemes, since they are obtained as a result of calculation mainly using computers.
The limiting conditions for strength are called inequalities that determine the limit limit for efforts. When such inequality turns into equality, the structural element to which the effort in question relates enters a new stage of work.
A necessary condition for applying the limit equilibrium method to calculate the load-bearing capacity of structures is a sufficiently significant increase in deformations in sections where the forces have reached the limit conditions.
A sufficient increase in deformations in sections or in zones should be considered the values or a set of values that ensure the growth of deformations in the structure after reaching the maximum load, when the structure turns into a kinematically variable system. The accumulation of deformations in the zones of their insignificant development occurs mainly due to:
- rotation of the normal or inclined section from the action of the bending moment (plastic hinge);
- shortening or elongation in normal sections from the action of longitudinal forces (plastic shortening or elongation);
- shear deformations along inclined sections from the action of transverse forces (plastic shear).
A combination of the main types of deformations in a state of extreme equilibrium of structures along normal or inclined sections is allowed.
To ensure conditions that meet the second prerequisite of the limit equilibrium method, i.e. the possibility of developing sufficient local deformations when the forces in the structural elements reach the limit conditions, the following rules must be observed:

1) design structures so that the cause of destruction could not be the destruction of the concrete of the compressed zone before the beginning of the rebar flow;
2) apply to the reinforcement of steel structures that allow sufficiently large deformations. This condition is met by fittings of class AII, AIII, BP with a two–line diagram, as well as fittings with a conditional yield strength of classes AIV - AVI, Bp II and a three-line diagram;
3) do not allow the use in statically indeterminate structures calculated by the limit equilibrium method of conventional and prestressed reinforcement that does not have adhesion to concrete (bundles, strands, rods and ropes in channels without injection with mortar, sprengel structures, drawn rods, etc.
4) select the main design sections, as well as the breakage points of the reinforcement in the elements working on the transverse load (beams, decking, racks compressed with a large eccentricity), so that the relative height of the compressed zone in strength is less than the boundary determined according to clause 3.7 [1-17].
This restriction does not apply to racks that do not carry crane or other cantilever loads and are compressed with a small eccentricity. It is justified in such a way that in risers, with their sufficient length and the absence of loads on the consoles, the transverse forces are small, and therefore the bending moments change slowly in height. In this regard, if the limiting condition in the most dangerous section turns into equality, then very noticeable local deformations will occur on a fairly large area of the adjacent site.
Accumulating over a relatively long length, these deformations will provide a sufficient angle of rotation between the sections limiting the area of large deformations on the rack. On the contrary, in elements operating on a transverse load or on a load applied to the consoles, significant transverse forces often act in places of maximum moments.
When the first prerequisite of the ultimate equilibrium method is fulfilled, the structures must be sufficiently rigid, however, the sign of sufficiency is not the operational requirements, but the degree of change in the equilibrium conditions due to the resulting deformations.
After the implementation of zones of concentrated deformations and fracture lines in the system, the system becomes kinematically changeable at the maximum load determined by the method of limit equilibrium, a set of states corresponds to various displacements of the system. Of this set, the method for determining displacement is the only one corresponding to the achievement of the ultimate value of deformation (angle of rotation, shortening, elongation or shear) in the last plastic connection, after which the system becomes kinematically changeable.
If it is necessary to take into account the deformations of the structure that develop before the exhaustion of the bearing capacity, then these deformations should be determined by calculation and to assess the strength of the structures, apply the method of ultimate equilibrium to the deformed (with modified geometry) system. In other words, it is necessary to consider the ultimate equilibrium not of the original (before the application of the load) structure, but the ultimate equilibrium of the new structure, the geometric characteristics of which have changed as a result of the manifested deformation.

Conclusion

When calculating by the method of limiting equilibrium of structures supporting and relying on bulk materials, it is allowed to accept the simultaneous achievement of limiting conditions in reinforced concrete and in bulk material (achievement in the ground of limiting tangential stresses along sliding lines).

Currently, in all the instructions for the calculation and design of reinforced concrete structures, it is allowed to take into account the phenomena of redistribution of efforts to a greater or lesser extent. The expansion of the use of new methods is facilitated by the fact that existing regulatory documents recommend taking into account the change in the distribution of forces caused by the occurrence of cracks and plastic properties of structures [2].

Despite the studies of reinforced concrete elements and structures carried out in the world practice, the issue of redistribution of efforts remains relevant at present. In connection with this, and the use of new high-strength reinforcing steels [3-34], it becomes necessary to clarify the established basic conditions and restrictions imposed on reinforced concrete structures when designing them, taking into account nonlinear work.

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