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Accident Prevention of Buildings and Structures Based on Two-Level Assessment of Bearing Capacity of Structures

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Abstract. The issues of prevention of emergency situations of buildings and structures caused by physical depreciation during long-term operation are considered. A two-level assessment of the bearing capacity of the members of structural systems of construction objects is proposed. The bearing capacity of structures has been determined by the variational method in the mechanics of a deformable solid. The design kinematic schemes, which reflect the behavior of structures in the ultimate state, are obtained. The boundary between unusable for normal operation and emergency technical conditions of separate structures and buildings as a whole is established unambiguously. It is proposed to prevent construction site accidents and remove structures from the emergency situation in two stages. At the first stage, the load is reduced by excluding its live component and the constructive (design) scheme of worn-out bearing members is necessarily corrected. At the second stage, the bearing capacity of structures is increased by strengthening and work is performed to protect them. In case of unsuitable technical condition, the strengthening can be performed without prior change of the structural scheme. The two-level assessment of the technical condition of structures and the sequence of removal of buildings and structures from the emergency condition are proposed.

INTRODUCTION

Along with new construction, it is necessary to pay attention to ensuring the safety and reliable operation of existing buildings and structures. Scientific works [1–6] are devoted to this question. Due to long-term operation, the physical depreciation of building structures leads to a significant reduction in their bearing capacity [7–9].

In the presence of intensive physical depreciation, structural safety and accident prevention of construction sites come first [10–14]. The collapse of structures poses a threat to human health and life and has a negative impact on the environment. Therefore, accident prevention is always better and more effective than eliminating their consequences. For the timely application of measures to preserve buildings and structures while reducing the bearing capacity of structures, it is necessary to reasonably determine their technical condition, which provides an appropriate list of measures to remove them from a dangerous situation. In the formulation of the characteristics of the technical condition for not suitable for normal operation and emergency there are no clear quantitative criteria for establishing the level of insecurity of bearing capacity. The characteristics "impossibility to guarantee the integrity of the structure" and "the possibility of ensuring the integrity" shift the choice of the state category on the intuition of the specialist who conducts the survey. However, even with experience and qualifications, a specialist may err in assessing the level of danger of the situation. Classification full-fledged features of a technical condition at decrease in bearing capacity of designs for most cases also do not define it unambiguously. This prevents the establishment of a list of the most effective measures in accordance with the actual technical condition.

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Therefore, determining a clear line between the technical condition of not suitable for normal operation and emergency is an urgent task. One of the areas of accident prevention is to clarify the bearing capacity of structures on a general theoretical basis, taking into account the impact of physical depreciation.

The purpose of this study is to establish a clear line between unusable and emergency conditions on the basis of a two-level assessment of bearing capacity, to provide proposals for the sequence of removal of structures from emergencies and accident prevention of buildings and structures.

THE METHOD OF TWO-LEVEL ASSESSMENT OF BEARING CAPACITY

The calculation of the first group of limit states to ensure the safety margin must ensure the preservation of the performance of structures of any material, taking into account the maximum possible level of loads and the minimum value of strength characteristics.

The calculation of bearing capacity is to check the condition

$$\Phi_{1,\max}(g_k, v_k, \gamma_f, \gamma_n, \psi, dc) \le \Phi\left(f_k, 1/\gamma_m, \gamma_c, S, k\right), \tag{1}$$

where $\Phi_{1,max}$ – power parameters from the action of the full ultimate design load, g_k and v_k – characteristic values of dead and live load, γ_f – load safety factor, γ_n – safety factor for responsibility of the building or structure, which is determined depending on the classes of failure consequences, ψ – load combination factor, dc – design scheme, Φ – estimated bearing capacity, f_k – characteristic resistance of the material, γ_m – safety factor for material, γ_c – coefficient that takes into account the operating conditions of the structure, S – geometric characteristics of the cross section, k – coefficient of impact of physical depreciation.

That is, the bearing capacity of the structure is determined by the fulfillment of the condition: the maximum values of bending moments M, shear V and longitudinal N forces in sections from the ultimate design values of loads should not exceed the design bearing capacity.

If the bearing capacity is not provided for the action of full load $\Phi_{1,\,max}$ (*the first level of insecurity*), but its security for the action of a dead load $\Phi_{2,\,max}$ and the ability to guarantee its integrity, the technical condition of the structure is defined as unfit for normal operation

$$\Phi_{1,\max}(g_k, v_k, \gamma_f, \gamma_n, \psi, dc) > \Phi\left(f_k, 1/\gamma_m, \gamma_c, S, k\right) \ge \Phi_{2,\max}(g_k, \gamma_f, \gamma_n, \psi, dc). \tag{2}$$

It is necessary to perform reinforcement of structures in the absence of live load, increasing the bearing capacity Φ to meet condition (1).

Prolonged operation of buildings and structures may lead to situations where even the cessation of use of facilities and the absence of live load does not guarantee the integrity of structures and their possible destruction. Then there is a need to adjust the design scheme of the bearing members.

Removal of structures from the state of emergency, in which the bearing capacity is not provided for the action of a dead load (the second level of insecurity)

$$\Phi_{2,\max}(g_k, \gamma_f, \gamma_n, \psi, dc) > \Phi\left(f_k, 1/\gamma_m, \gamma_c, S, k\right) \tag{3}$$

is carried out in two stages:

- first, the values of the parameters of the left part of inequality (1) are reduced by eliminating the variable component of the load and mandatory change of the calculation scheme for a positive redistribution of force
- parameters, namely bending moments M, shear V or longitudinal N forces to a level at which bearing capacity for the action of only a dead load is provided (2);
- secondly, the values of the ultimate forces Φ, which are perceived by the structures by their reinforcement, increase until the fulfillment of condition (1).

Thus, to justify the application of measures to preserve objects on the basis of a decrease in the bearing capacity of structures, it is proposed to establish two levels of insecurity of bearing capacity: for full load and without taking into account the live load, which at the termination of operation can be excluded. If the bearing capacity is not provided and only a dead load is applied, the predicted strength reserves are absent, it is impossible to guarantee the integrity and preservation of objects without taking measures to change the design scheme of structural system members with redistribution of power parameters *M*, *V* and *N* and reducing their values.

Reinforcement of emergency structures, which do not accept the load limited by a constant value, by leaning and hanging additional elements on them increases significantly the weight of the structure before the inclusion of reinforcement in the work, which takes some time. This occurs when creating pre-stress in horizontal and trussing rods or when laying new concrete before its hardening in the case of increasing the working height and increasing the cross section of reinforced concrete and masonry structures and can lead to the destruction before the desired effect.

Therefore, for emergency structures, it is mandatory to pre-change the design schemes to reduce the values of power parameters from external loads. At the same time, unloading elements should be leaned on a design, which can accept additional loading.

VARIATIONAL METHOD OF STRENGTH ASSESSMENT

To refine the bearing capacity of concrete, reinforced concrete, masonry and reinforced masonry structures, it is proposed to use the variational method in the theory of plasticity, developed at the National University "Yuri Kondratyuk Poltava Polytechnic" [15–17]. It is based on the concept of rigid-plastic body. Plastic strains are considered localized in a thin layer on the failure surface, adjacent areas are taken absolutely rigid. Extreme properties of materials are used to determine the ultimate load.

The principle of virtual velocities is applied, at which the ultimate forces perceived by structures correspond to the minimum power of plastic strain.

The functional of the principle of virtual velocities is investigated at steady state using the variational equation [16]

$$\delta J = \int_V (TH' + \sigma\xi' + \rho(\omega_i - g_i)\upsilon_i')dV - \int_{S_F} f_i^* \upsilon_i' dS = 0, \tag{4}$$

where T and H' – intensity of tangential stresses and shear strain velocities, σ and ξ' – hydrostatic (average) stress and volumetric strain, υ_i' – kinematically possible velocities, V – body volume, ρ, ω_i and g_i – mass density of the deformable material, components of the vector of motion acceleration and mass force, S_F – the area of the surface on which the forces f_i^*. are set.

Only the values of the deformation parameters, the ratio of the velocities of the hard disks υ_2/υ_1, the angle of the velocity vector υ to the failure surface and the angle of inclination of the velocity gap γ vary.

The method is based on a general theoretical basis, which provides increased accuracy of calculation and avoidance of errors that occur in the empirical approach due to the limitation of the scope of its calculation dependencies. It allows you to solve strength problems for different elements under the shear [18–20].

The concrete is considered as a rigid-plastic body. Plastic strains are considered to be localized in thin layers on the failure surface of concrete and reinforced concrete members.

The virtual velocities principle is used.

Ultimate state simultaneous existence condition on failure entire surface is criterion for plasticity theory applicability.

The influence of reinforcement that crosses the shear surface on the strength of reinforced concrete elements is taken into account by compression.

As examples of application of the variational method the kinematic schemes of failure of compressed and flexural members under the shear failure are given (Fig. 1).

The design dependences for determining the ultimate load value are given in [16–20]. The ultimate values of normal σ_n and tangential τ_n stresses on the failure surface and principal stresses σ_1 in compressed zones at given σ_2, stresses σ and τ at the ends of the elements are in accordance with the accepted Balandin-Genius strength condition, which is considered as a plasticity condition.

The stress values in the tensile zone are equal to the value of the axial tensile strength f_{ct}. The impact of the reinforcement is taken into account by external compression

By varying the level of compression, it is possible to change the location in the structures of the most stressful areas according to the character and location of defects and damage, which reduces their impact.

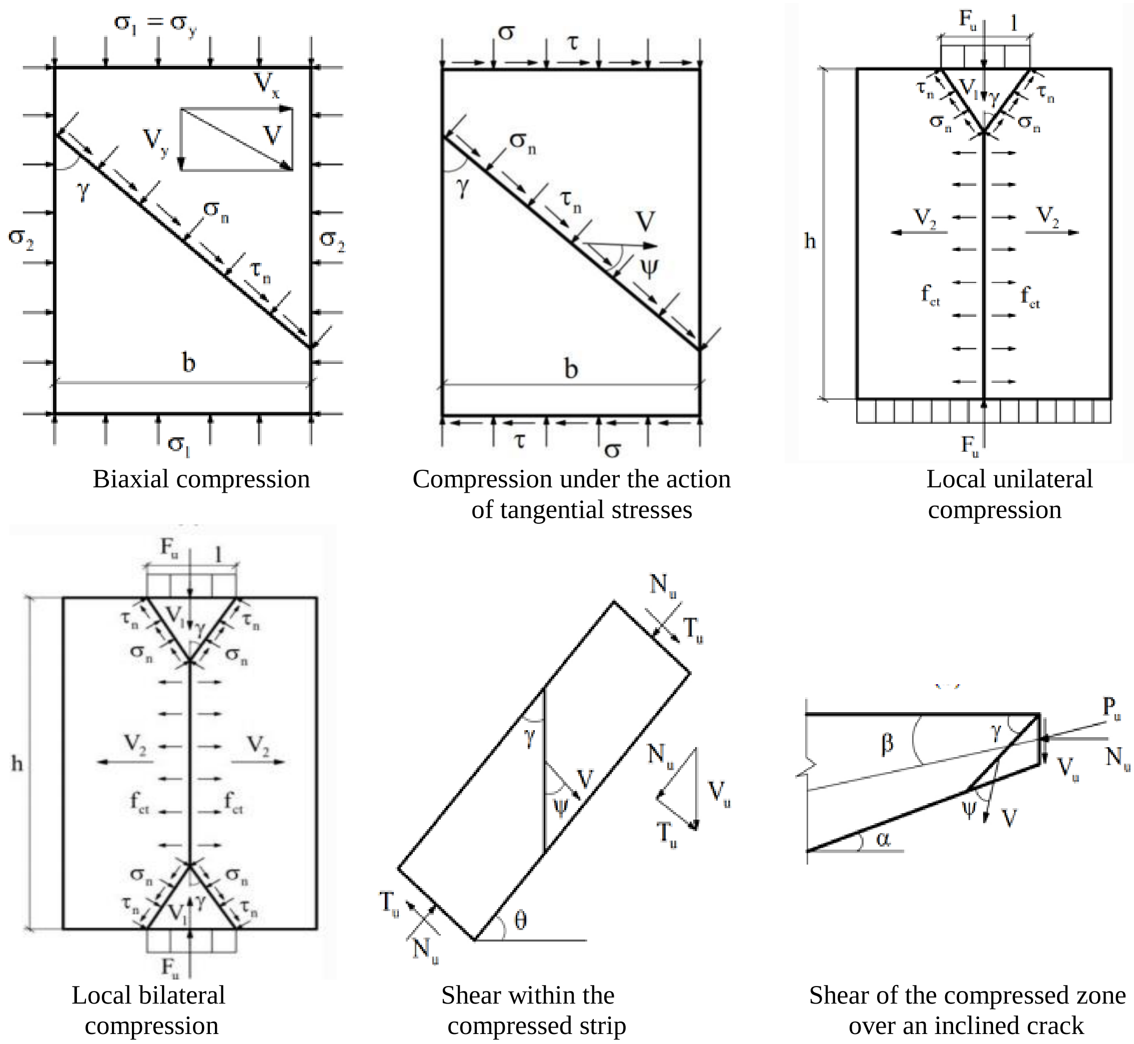


FIGURE 1. Kinematic failure schemes of concrete and masonry elements.

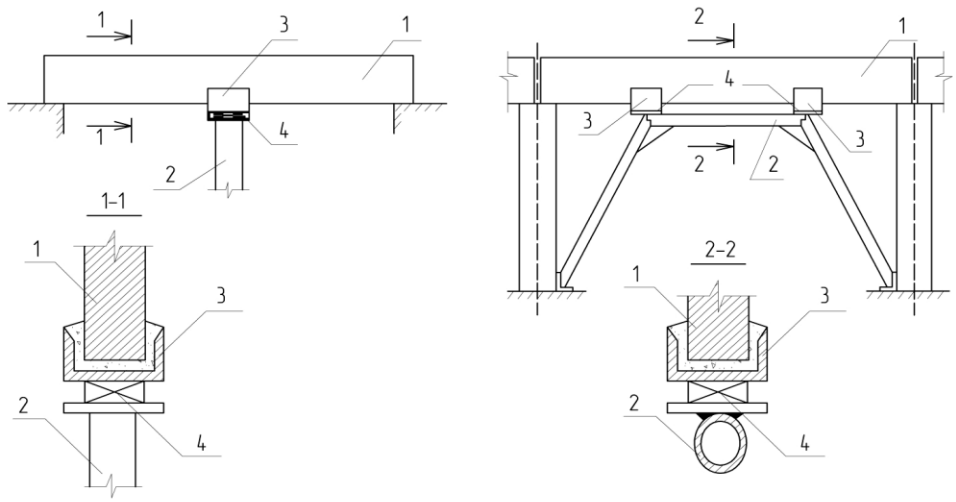
EXAMPLE OF REMOVING THE STRUCTURE FROM THE EMERGENCY STATE

As an example, we consider a flexural reinforced concrete member, which is in a state of emergency and is characterized by the inability to guarantee the integrity of the structure before reinforcement – the lack of bearing capacity to act only a dead value of the load according to inequality (3).

Therefore, accident prevention measures must be carried out in two stages:

- to unload the beam by eliminating the action of live load, to reduce the value of the shear force and bending moment in the dangerous sections of the beam by changing its design scheme (Fig. 2)

Two variants of change of the design scheme are considered: installation of an unloading rack and a portal frame. Based on the results of the calculation, taking into account the corrosion damage of the longitudinal and shear reinforcement and ensuring the safety of the structures to which the load is transferred, the best option is selected – supply under the beam of the portal frame. The unloading frame leans on the structures, the bearing capacity of which is provided. After installation of a portal frame and reduction of values of M and V in the most dangerous sections of a beam, its bearing capacity on action of only dead loading is provided. These measures must be performed with the involvement of specially trained emergency response teams;



Unloading rack Portal frame

FIGURE 2. Changing the design scheme of the beam by summing up the additional elements:
1 – reinforcing beam; 2 – additional support; 3 – support element from a channel; 4 – steel wedges.

– to strengthen a beam by installation of a trussing rod (Fig. 3) for maintenance of bearing capacity on action of total loading. Inclusion of strengthening elements in work is carried out by creation of pre-stressing in branches of a trussing rod at their convergence among themselves by the coupling device in the middle of span of a beam on the size defined by calculation.

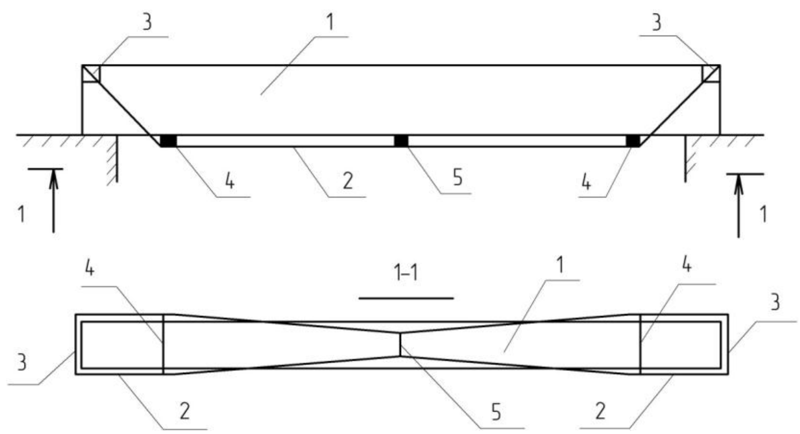


FIGURE 3. Reinforcement of the beam with a steel a trussing rod:
1 – reinforcing beam; 2 – pre-stressed rod; 3 – support element; 4 – stud; 5 – coupling stirrup.

When the structures of one-storey buildings and structures approach the emergency condition in the winter period of the year, the object is decommissioned, live loads are minimized, conservation measures are carried out, and strengthening works are carried out in the summer period of the year.

CONCLUSIONS

To prevent accidents of buildings and structures and prevent their collapse due to failures, as well as to ensure long-term reliable operation a refined two-level assessment of bearing capacity of structures should be applied based on the variation method in the mechanics of deformable solids, which allows to take into account the specifics of the stress-strain state and the best way to redistribute the force parameters in the elements with their decrease in the most stress zones.

In the case of ensuring the bearing capacity of structural elements only under the action of a dead load, if possible to guarantee their integrity, to preserve the objects measures to increase bearing capacity are effective by strengthening the structure using a variation method for refined assessment. It is essential to ensure that the reinforcement elements work together with the existing structures.

Decommissioning of individual structures and buildings and structures in general in the case of failure to provide bearing capacity and the action of only a dead load and the inability to guarantee their integrity must be carried out in two stages. At the first stage, the live loads are reduced as much as possible, the design schemes of the elements of structural systems are adjusted in order to reduce the value of the force parameters *M*, *V* and *N* by installing additional unloading elements for their redistribution. At the second stage, the structures are directly reinforced in order to increase their bearing capacity and their protection is performed.

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