Evaluation of the deformability of balcony plates of monolithic residential buildings

Anna Malakhova$^1$ and Dmitry Malakhov$^2$

$^1$ Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia
E-mail: gbk@mgsu.ru.

$^2$ Design and mechanical faculty. The Moscow Automobile and Road State Technical University (MADI), Moscow, Russian Federation, Leningradsky Prosp., 64.
E-mail: malahow_dm@mail.ru.

Abstract. The calculation and design solutions of balconies of modern monolithic residential buildings are considered. Such balconies are part of a monolithic floor slab, which relies on internal supporting vertical structures. They have a larger extension, and when using brick walls to fence balconies - and more loading. The experience of operating monolithic residential buildings with balconies with their removal of 1.2 ... 2.5 m and a brick balcony railing with a two-chamber stained-glass window showed the possibility of increased deformations of the balcony cantilever sections of the floor slabs of such buildings. If for such balconies the maximum deflection provided by the project for the balcony cantilever sections of the slab will be close to the maximum permissible values, then deviations from the design that were allowed during the construction of the building (reducing the class of concrete versus design, changing the location of the working reinforcement of the slab during concreting) can lead to increased deflection of balconies. Computer modeling allows you to accurately reflect the real work of the structure, and performing calculations in a nonlinear setting - to obtain an adequate deflection of the console balcony slab. The main approaches to modeling the design scheme of a flat floor slab with a balcony part are considered for determining plate deformations taking into account non-linear deformation of materials, as well as taking into account plate reinforcement.

Balconies, their enclosures are an essential element of many residential and public buildings. Their appearance and technical condition affect not only the architectural appearance of the building, but also seriously affect the degree of operational reliability of the building, the degree of comfort of the organization of the living space of the rooms.

However, during the operation of the building, its structures, including the construction of balconies, are subject to mechanical damage, their materials age and collapse due to environmental influences (temperature, precipitation, exposure to chemicals, etc.).

Computer simulation of the work of building structures helps to determine the technical condition of building structures, including - balconies; it in combination with verification calculations allows you to identify the degree of damage, possible causes of damage, identify ways and methods of eliminating them (restoration of bearing capacity, restoration of appearance, etc.).
The design solutions of the balconies correspond to the construction periods of the construction of buildings. Until the 90s of the last century, large-panel, rarely large-block or brick residential buildings prevailed. The balconies of such buildings were designed open, had a relatively small extension and a light enclosure (figure 1, a).

The outer walls in buildings with balconies were load-bearing or self-supporting. Flat reinforced concrete balcony slabs mated tightly with them. Figure 1, b shows a constructive solution for the interface unit of a flat reinforced concrete slab of a balcony with a brick wall. The balcony slab rests on the wall and mates with the anchor outlets made from the beam foundation sill of window.

Figure 1. Balconies of a block building (a); constructive solution of the interface unit of the balcony slab with the wall of a brick building (b): 1 - reinforced concrete slab of the balcony; 2 - the location of the working reinforcing bars in the balcony slab; 3 - multi-hollow floor slab; 4 - connecting anchor

In subsequent years, first on the initiative of residents, and then, during the planned repair of building facades, glazing of balconies was organized, which helped protect reinforced concrete balcony slabs from atmospheric influences, but increased the load on the balcony slabs [1].

The next construction period is associated with the construction of monolithic residential buildings. Figure 2a shows the balcony of a modern monolithic residential building.

The balconies of such buildings are part of a monolithic floor slab, which is supported by internal supporting vertical structures. External walls are multilayer non-bearing and are installed floor by floor on the floor slabs of buildings. Compared to the balconies of the previous construction period, the balconies of modern buildings have a larger extension, and when using brick walls to enclose the balconies, they have a greater load.

The experience of operating monolithic residential buildings with balconies with their removal of 1.2 ... 2.5 m and a brick balcony enclosure with a two-chamber stained-glass window showed the possibility of increased deformations of the balcony cantilever sections of the floor slabs of such buildings.

If with such a constructive solution of balconies, the maximum deflection of the balcony cantilever sections of the slab provided by the project (on the free edge of the console) will be close to the maximum permissible values, then deviations from the design that were allowed during the construction of the building (decrease in the class of concrete against the design, change in the location of the working reinforcement of the slab during concreting ) can lead to increased deflection of balconies.
Figure 2, b shows a photograph of the junction of the brick enclosure of the balcony to the front wall of the building. It is seen that along the junction line of the brick fencing of the balcony to the front wall of the building, a crack formed with an opening width of up to 25 mm.

The technical condition of the balcony slabs of this building was evaluated as limited-functioning, and a numerical calculation was made to assess the degree of deformability of the balcony slabs, to identify possible causes of increased deformations of individual balcony slabs, and also to take into account the degree of influence of various factors on the deformations of the balconies of the monolithic residential building.

Numerical calculation was performed in the LIRA-SAPR software package [2] taking into account the physical nonlinearity of materials and the reinforcement of the floor slab, including its balcony cantilever part. In this case, deformations along the edge of the balcony extension (free end of the slab) were evaluated.

In accordance with building codes [3], the deflection of the balcony cantilever part of the slab must be such as to ensure the safety of the balcony fence. Thus, both constructive and aesthetic-psychological requirements should be presented to the deflection of the balcony of the building.

Figure 3 shows a fragment of the reinforcement of a flat slab of the surveyed building. A 180 mm thick floor slab has holes of 200-600 mm in size for placement of thermal insulation in them. The slab is made of concrete of class B25 and is reinforced with knitted grids located at the upper edge (grid
Grids C1 and C2 are composed of \( \varnothing 8A500 \) reinforcing bars laid perpendicular to each other with a pitch of \( S = 200 \) mm. The upper grid C1 in the support zones of the slab has additional reinforcing bars \( \varnothing 8A500 \), laid perpendicular to each other with a pitch of \( S = 200 \) mm. To frame the holes designed to accommodate the thermal insulation, reinforcing bars of a frame 2-16A500 with a pitch of \( S = 50 \) mm are installed along the long sides of the holes.

The fragment shows that the coupling of the balcony cantilever section of the slab with the slab of the floor inside the building was performed using the K1 framework, which is considered to be installed in fictitious beams with a cross-sectional dimension of 200-180 \((h)\) mm. The longitudinal reinforcement of the K1 frame is four \( \varnothing 16A500 \) bars, and the transverse \( \varnothing 6A240 \) bars installed with a pitch of \( S = 100 \) mm.

Example of the design of flat monolithic floor slabs are given in [4, 5]. General recommendations for the design of flat monolithic floor slabs are given in [6].

It should be noted that when performing numerical calculations in accordance with the recommendations given in [7], the floor slab is initially calculated in the elastic setting, but with a decrease in the value of the initial modulus of elasticity of concrete, specified in the software package when describing the stiffness of the elements of the calculation scheme.
At the initial stage of the calculation, the design parameters of a flat monolithic floor slab should also be clarified, which include: the thickness of the slab, the classes of concrete and reinforcement, and the percentage of reinforcement.

In the verification calculation, the thickness of the floor slab was assigned (in accordance with the results of the survey) 180 mm, the concrete class was B25, the reinforcement class was A500. For the reinforcement scheme of a flat monolithic slab shown in Figure 3, the following reinforcement parameters took place: \( \mu\% = 0.19\% \) - main reinforcement, \( \mu\% = 0.38\% \) - reinforcement of the support zone of the slab, \( \mu\% = 1.5\% \) - reinforcement of the fictitious beam, \( \mu\% = 2.2\% \) - reinforcement of the area of the frame of the holes.

At subsequent stages of the calculation with known reinforcement, numerical calculations in a nonlinear formulation were performed. In this case, the laws of deformation of concrete and reinforcement of the assigned classes were selected from the LIRA-SAP PK library and the reinforcement of elements of the design scheme was described [2].

The choice of the law of deformation of materials was made in accordance with the recommendations given in [8]. To describe the nonlinear deformed state of materials, a piecewise linear law (three-line or two-line diagram) or an exponential law can be chosen. The reinforcement parameter for elements of the design scheme can be assigned both by indicating the area of the working reinforcement and by setting the percentage of reinforcement.

Figure 4 shows a fragment of the design scheme of a flat floor slab with a balcony part. The slab rests on the pylon rods, the cross section of which is set using the ARB command (absolutely rigid body). Fictitious beams in the design scheme are modeled by bar elements.

When assessing the magnitude of the deflection of the free edge of the balcony, holes designed to accommodate the thermal insulation were modeled in the design scheme. These holes were located under the external curtain walls of the building. For the finite elements of different sections of the
design scheme, the corresponding percentage of reinforcement was assigned; an exponential law was chosen to describe the nonlinear deformation of concrete, and a piecewise linear law to describe the nonlinear deformation of reinforcement.

**Conclusions**

The study of the deformability of building floor slabs in linear and nonlinear formulations with the construction of computer models is very relevant and clear. It is undertaken to study the degree of influence of changes in the structural parameters of building structures (including flat monolithic ceilings [9]) on their deformation, as well as to expand the capabilities of the calculation model to describe the nature of its deformation [10, 11].

The article considers the main approaches to modeling the design scheme of a flat floor slab with a balcony part to determine the deformation of the slab taking into account non-linear deformation of materials, as well as taking into account the reinforcement of the slab designated according to the results of strength calculation.

Computer modeling allows you to accurately reflect the real work of the structure, and performing calculations in a nonlinear setting - to obtain an adequate amount of deflection of the console balcony slab. This is important for calculating balconies of modern multi-story monolithic residential buildings with a large extension and significant strip loading from the brick walls of the enclosure and stained-glass window of the balcony glazing, which means, accordingly, the deflection, which is close to the maximum permissible value.

**References**

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